Application ID 14-1772467 LED Lighting: M&V Report

August 5, 2016

Duke Energy Carolina
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.
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Introduction

This report addresses M&V activities for lighting retrofit energy conservation measures (ECMs), conducted as part of the [redacted] Smart $aver custom incentive program application; specifically, the replacement of fluorescent lighting fixtures with LEDs at three [redacted] locations in South Carolina.

ECMs—Replace Fluorescent Lighting Fixtures with LEDs

The customer replaced 39 four-lamp, 2'x4', 160-Watt T12 lighting fixtures with 39 two-lamp, 4-foot 44-watt LED lighting fixtures.

Goals and Objectives

Table 1 summarizes projected savings goals identified in the project application.

Table 1. Project Goals

ECM	Applicant		Duke Energy		
	Annual kWh Savings	Avg. kW Reduction	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1	7,849	1.7	8,353	1.8	1.8
2	5,756	1.3	6,126	1.3	1.3
3	6,803	1.5	7,240	1.6	1.6
Total	**20,408**	**4.5**	**21,719**	**4.7**	**4.7**

The M&V project sought to verify the actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization rates (kW and kWh)

Project Contacts

The Duke Energy contact listed in Table 2 granted approval to plan and to schedule the site visit for this M&V effort.

Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Frankie Diersing	office: 513-287-4096 Frankie.diersing@duke-energy.com
Cadmus	Christie Amero	office: 303-389-2509 Christie.amero@cadmusgroup.com
Customer	redacted	

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Site Location

The locations where these measures were installed are shown in Table 4.

Table 3. Project Locations

Address	ECM
redacted	1
redacted	2
redacted	3

M&V Option

To assess this project, Cadmus utilized IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visits for the three locations. Tom Davis of Cadmus performed the site visits on January 4, 2016.

Field Notes

As the three locations were retail stores, store clerks made much of the on-site personnel. Facility descriptions are based only on Cadmus' observations. While on site, Cadmus installed lighting loggers to monitor the ECMs' hours of use.

Field Data

Cadmus performed a walkthrough of each location to verify and count the new lighting fixtures and to install light loggers.

In each facility, Cadmus installed light loggers to collect fixture operating hours over two weeks. Table 4 summarizes the fixture quantities and locations of installed light loggers.

Table 4. Summary of Light Logger Metered Data

Site	Meter S/N	Location	Metered Hours	Operating Hours	Percentage Operating	Projected Annual Operating Hours	CF
redacted	10380404	Main store	322	119	37%	3,229	86%
	10380529	Bathroom	322	1	0%	15	0%
	10380569	Main store	322	119	37%	3,231	86%
	10380600	Back storage	322	17	5%	449	6%
redacted	10268288	Cigar room	322	322	100%	8,760	100%
	10380396	Main store	322	129	40%	3,518	86%
	10380414	Bathroom	322	35	11%	941	12%
	10380607	Main store	322	128	40%	3,497	86%

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Site	Meter S/N	Location	Metered Hours	Operating Hours	Percentage Operating	Projected Annual Operating Hours	CF
redacted	10380406	Main store	322	0	0%	12	0%
	10380394	Back room	322	27	8%	743	70%
	10380407	Cigar room	322	120	37%	3,281	86%
	10380411	Main store	322	120	37%	3,281	86%
	10380412	Main store	322	121	38%	3,295	86%

Data Analysis

Cadmus used the survey and light logger data to verify the demand and operating hours of the installed lighting fixtures and applied waste heat factors to final numbers to account for HVAC interactive effects. Table 5 summarizes the energy savings calculations.

Table 5. Energy Savings Calculations

Actual Operating Hours	CF	Quantity	Demand, kW		Energy Savings		
			Pre	Post	Average kW Reduction	CP kW Reduction	Annual kWh
2,635	61%	15	0.16	0.04	1.8	1.1	4,743
		13	0.16	0.04	1.6	1.0	4,111
		11	0.16	0.04	1.3	0.8	3,478
Total*					**5.3**	**3.2**	**13,602**

* Includes HVAC interactive effects.

Conclusion

Cadmus found the equipment installed as expected. The overall energy savings realization ratio was 68% compared to Duke Energy's claimed savings. The summer peak demand realization rates were calculated as 63%. The average (or noncoincident) peak demand reduction realization ratio was 113%.

Energy savings were reduced due to the original analysis assuming a greater number of operating hours than the facility actually operates.

Table 6 provides a comparison of the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction.

Table 7 provides the realization rates compared to energy savings and demand reductions claimed by Duke Energy.

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Table 6. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

ECM	Applicant		Duke Energy Claimed			Evaluation		
	Annual kWh Savings	Avg. kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	7,849	1.7	8,353	1.8	1.8	4,743	1.1	1.8
2	5,756	1.3	6,126	1.3	1.3	4,111	1.0	1.6
3	6,803	1.5	7,240	1.6	1.6	3,478	0.8	1.3
Total*	**20,408**	**4.5**	**21,696**	**4.7**	**4.7**	**13,602**	**3.2**	**5.3**

* Includes HVAC interactive effects.

Table 7. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW	Non-Coincident Peak kW
63%	68%	113%

Application ID 13-1358865
Lighting
M&V Report

August 26, 2016

Duke Energy
139 East Fourth Street
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Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for three retrofit energy conservation measures (ECMs) included as part of the [redacted], Smart $aver custom incentive program application. Specifically, [redacted], a property management company, performed a lighting retrofit at its [redacted] building in North Carolina, and expected to save energy as a result of reduced fixture operating hours.

The three-story office building is occupied mainly from Monday through Friday during normal business hours. The building's annual electric energy use is 6,639,000 kWh, based on utility data for 2012 and 2013. Descriptions of the three ECMs as submitted in the application documentation are provided below.

ECM-1: Relocate 8,760-Hour Lighting Circuits to New Panels with Scheduling

Pre-Retrofit: The site previously used 222 non-emergency lighting fixtures on emergency lighting panels, which caused the lights to operate 24 hours per day, seven days per week, even though the spaces were occupied only during normal business hours.

The original analysis assumed that all 222 fixtures were two-lamp, 4-foot fluorescent fixtures with 32-watt T8 lamps. The fixture input was assumed to be 59 watts.

Installed: This measure involved relocating the 222 lighting fixture circuits to new relay panels. This allowed the facility to schedule the fixtures to turn off during unoccupied periods. The original analysis claimed updated lighting fixture operating hours as follows:

- First floor (24 fixtures): 13 hours per day, Monday through Friday, or 3,380 hours per year
- Second floor (127 fixtures): 13 hours per day, Monday through Friday, or 3,380 hours per year
- Third floor (71 fixtures): 13.6 hours per day, Monday through Friday, or 3,536 hours per year

Energy savings were expected to result from reduced lighting fixture operating hours, being turned off overnight and on weekends. This measure did not produce peak demand reduction, as fixtures were operated during the peak period.

ECM-2: Replace Parking Lot Photocells with Timeclock Controls

Pre-Retrofit: The site's exterior parking lot lighting fixtures were controlled by photocells, which automatically enabled lighting fixtures when ambient light levels decreased. Twelve of the fixtures were located in a remote parking lot, with no overnight use and minimal weekend use, as additional parking is located closer to the building.

The original analysis assumed that all 12 fixtures had an input of 1,150 watts.

Installed: This measure involved replacing photocells for the 12 fixtures with timeclock controls, which the facility programmed to turn the fixtures off overnight and on weekends. Programmed fixture operating hours were six hours per evening, weekdays only.

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Energy savings were expected to result from reduced fixture operating hours, used only for a limited time overnight and not on weekends. This measure did not produce peak demand reduction, as the exterior lighting was not operated during the peak period (both pre-retrofit and installed).

ECM-3: Install New Lighting Control System with Zone Control

Pre-Retrofit: The site's pre-retrofit, single-zone, lighting control system was based on each building wing. This control strategy forced most lighting fixtures to stay on longer than necessary, when some zones were occupied longer than others. Table 1 shows pre-retrofit operating hour assumptions.

The original analysis assumed that all controlled 3,525 lighting fixtures were two-lamp, 32-watt T8 fixtures with a total input of 59 watts.

Installed: The measure involved installing a new, multi-zone lighting control system, which allowed the facility to program different schedules for each zone in each wing and to reduce lighting fixture operating hours. Table 1 summarizes the assumed, installed fixture operating hours for each zone.

Table 1. Zone Controls—Pre-Retrofit and Installed Fixture Operating Hours

Floor	Wing	Zone	Operating Hours Per Week		Percentage Reduction
			Pre-Retrofit	Installed	
1	Purple	1	99.8	55.0	45%
		2		65.0	35%
		3		55.0	45%
	Blue	1	76.4	55.0	28%
	Red	1	168.0	55.0	67%
		2		65.0	61%
		3		75.5	55%
	Teal	1	113.9	65.0	43%
2	Purple	1	168.0	84.0	50%
	Blue	1	93.8	65.0	31%
		2		70.0	25%
		3		79.0	16%
	Red	1	92.3	55.0	40%
		2		55.0	40%
		3		65.0	30%
		4		85.0	8%
		5		64.0	31%
		6		60.0	35%
		7		70.0	24%
	Teal	1	65.8	55.0	16%
		2		52.5	20%
		3		62.5	5%
3	Purple	1	81.0	69.0	15%
	Blue	1	93.0	93.0	0%

Floor	Wing	Zone	Operating Hours Per Week		Percentage Reduction
			Pre-Retrofit	Installed	
		2		60.0	35%
		3		73.0	22%
	Middle	1	96.5	79.0	18%
	Red	1	96.5	55.0	43%
		2		69.0	28%
		3		52.5	46%
	Teal	1	80.0	60.0	25%
		2		66.0	18%

Goals and Objectives

Table 2 shows the projected savings goals identified in the project application.

Table 2. Project Goals

ECM	Application		Duke Energy			
	Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1	75,730	N/A	69,786	69,451	0	7.96
2	38,916	N/A	38,916	39,533	0	0.32
3	385,638	N/A	355,511	360,080	0	30.83
Total	**500,284**	**N/A**	**464,213**	**469,065**	**0**	**39.11**

* Source: DSMore input spreadsheet.

For this M&V project, Cadmus sought to verify actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

Project Contacts

Table 3 lists the Duke Energy contact who granted Cadmus approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

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Table 3. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 4.

Table 4. Site Location

Address	ECM
redacted	1, 2, & 3

M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. Christie Amero of Cadmus performed the site visit on June 24, 2016.

Field Survey

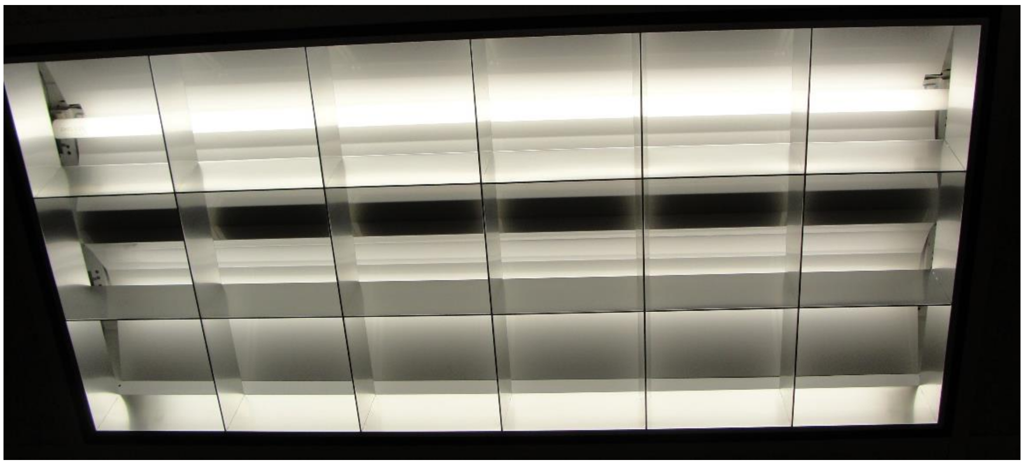
During the site visit, Cadmus met with the facility manager to review the lighting survey and to collect general operating information. The three-story building is laid out in an "X" shape with four separate wings: red, blue, purple, and teal. There is currently one tenant leasing the red, blue, and purple wings. The teal wing is completely unoccupied and there are no new tenants to fill the space. The third floor of the red wing is also unoccupied.

Most of the areas in the building are occupied during typical office hours (Monday through Friday, 7:00 a.m. to 6:00 p.m.). The building is closed on all federal holidays. The interior lighting fixtures are controlled by a central EMS and most lighting zones are programmed to be in "occupied" mode from 6:00 a.m. to 11:00 p.m., Monday through Sunday. There are 12 electrical panels controlling the lighting fixtures in the building (one on each floor of each wing). The exterior parking lot pole and wall pack lighting fixtures are also controlled by the central EMS.

Cooling for the building is provided by two 450-ton variable speed chillers. According to the facility manager, the chillers were installed less than three years ago. The cooling system uses economizer control to provide free cooling when outside air conditions allow. Heating is provided by electric perimeter reheat coils only. Conditioned air is distributed to the zones by variable air volume (VAV) boxes. There are approximately 14 VAV boxes per building floor, and only half are equipped with electric heating coils.

Most of the existing lighting fixtures in the offices and hallways are two-lamp, 2-foot by 4-foot parabolic troffers with fluorescent T8 lamps (see Figure 1). The lamps are EiKO model F32T8/841K and the ballasts are GE232MAXP-N/ULTRA. The total fixture input is 54 watts. Many of the downlights in the central lobbies and elevators were recently converted to LED.

Figure 1. Existing Parabolic Troffer with T8 Lamps



Field Data

After completing the lighting survey, Cadmus reviewed the central lighting control system and recorded current schedules, performed a walkthrough of the facility to verify the existing interior and exterior lighting fixture types, and installed light loggers on a sample of interior fixtures. A summary of the field data we collected for each ECM is provided below.

ECM-1: Relocate 8,760-Hour Lighting Circuits to New Panels with Scheduling

In order to estimate the number of lighting fixtures currently on emergency circuits, Cadmus counted the lighting fixtures that were on in the teal wing, since only the emergency fixtures were energized. There were 31 fixtures on in the first floor and 25 fixtures on in the third floor. There was construction on the second floor and some of the non-emergency fixtures were on, so we did not count the second floor. According to the facility manager, the number of emergency fixtures should be approximately the same in each wing.

ECM-2: Replace Parking Lot Photocells with Timeclock Controls

There are seven two-lamp high pressure sodium (HPS) pole fixtures and two one-lamp HPS pole fixtures in the overflow lot. Figure 2 shows one of the HPS pole fixtures in the remote lot.

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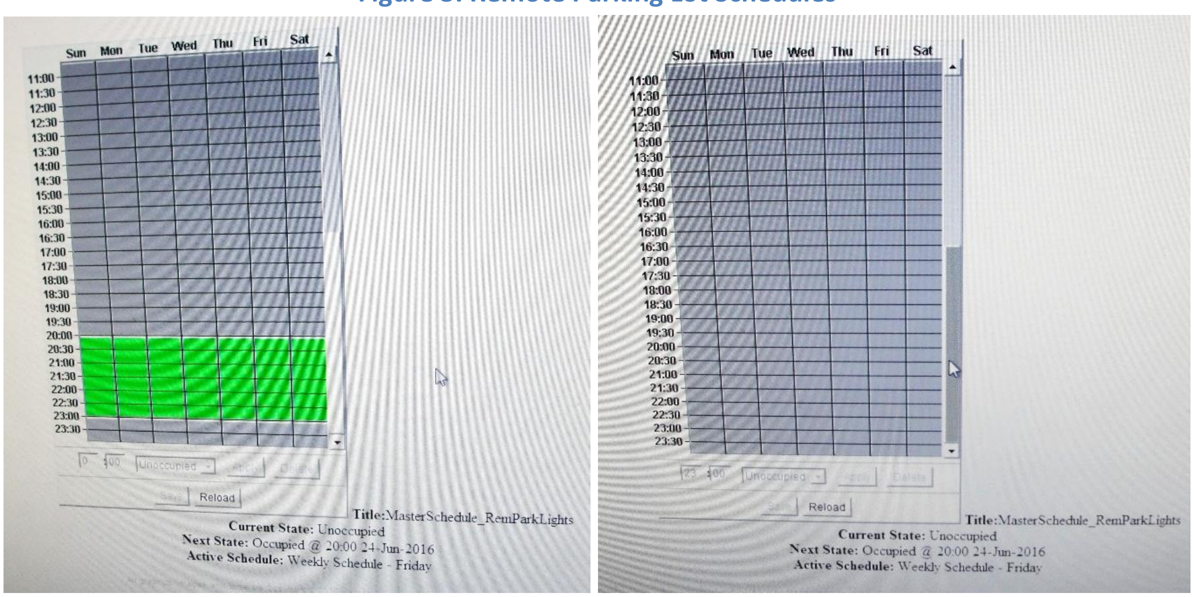
Figure 2. Remote Parking Lot

While reviewing the lighting control schedules during the site visit, Cadmus identified that the exterior lighting fixtures in the overflow parking lot were on timeclock control from 8:00 p.m. to 11:00 p.m. during the summer months and from 5:00 p.m. to 11:00 p.m. during the winter months. However, the facility manager pointed out that this parking lot has been closed due to reduced occupancy in the building and the lights are not required. The facility manager adjusted the timeclock schedule to keep the exterior fixtures in the overflow lot off at all times. Figure 3 shows the original and adjusted timeclock schedules.

Figure 3. Remote Parking Lot Schedules



ECM-3: Install New Lighting Control System with Zone Control

Cadmus reviewed the central lighting control schedule and installed five light loggers to evaluate the energy savings from this measure. Figure 4 shows the red and blue wings' first floor layouts and current schedules. According to the central controls, the lighting fixtures in all zones of the blue wing are scheduled to be on from 6:00 a.m. to 11:00 p.m., Monday through Sunday. Figure 5 shows the purple and teal wings' first floor layouts and current schedules. The teal wing is currently unoccupied.

Figure 4. Red (left) and Blue (right) Wings' Lighting Schedules

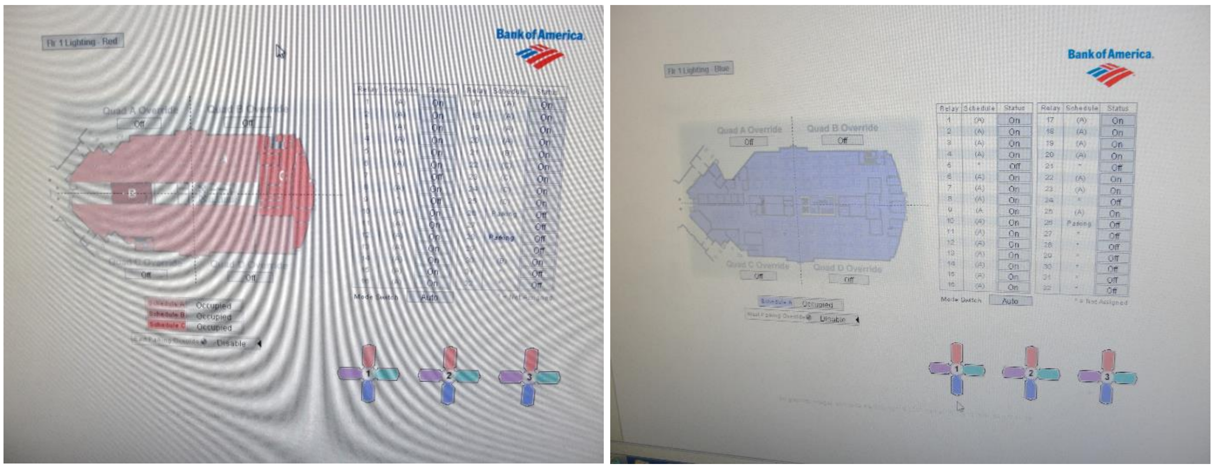


Figure 5. Purple (left) and Teal (right) Wings' Lighting Schedules

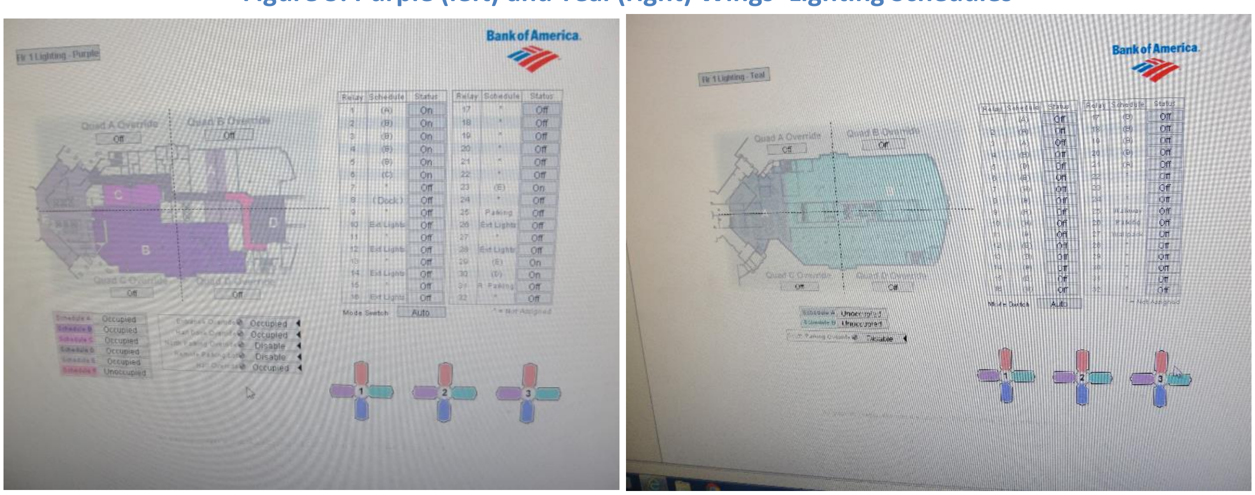


Figure 6 shows the hourly breakdown of the lighting schedule for a zone of the red wing (zone 1A).

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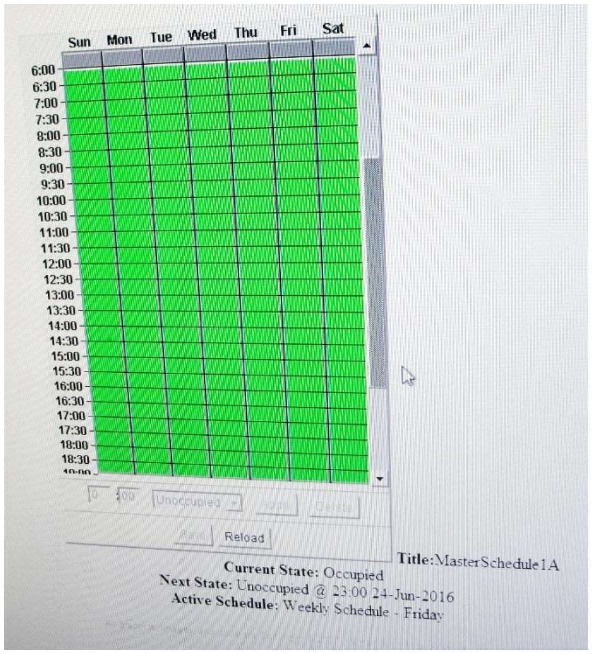
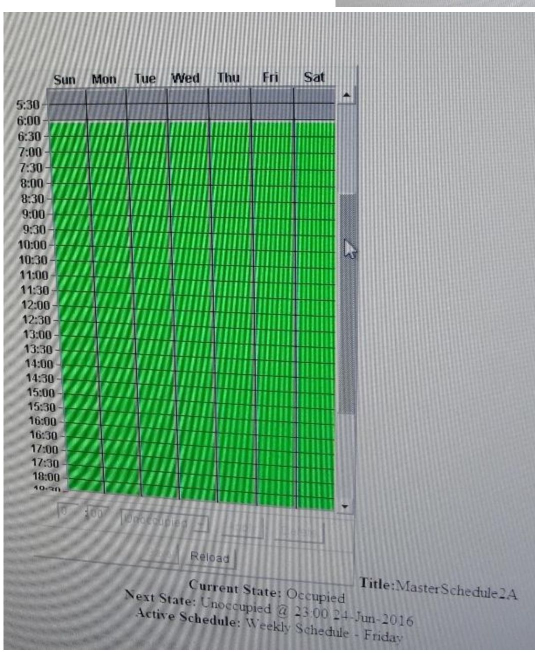
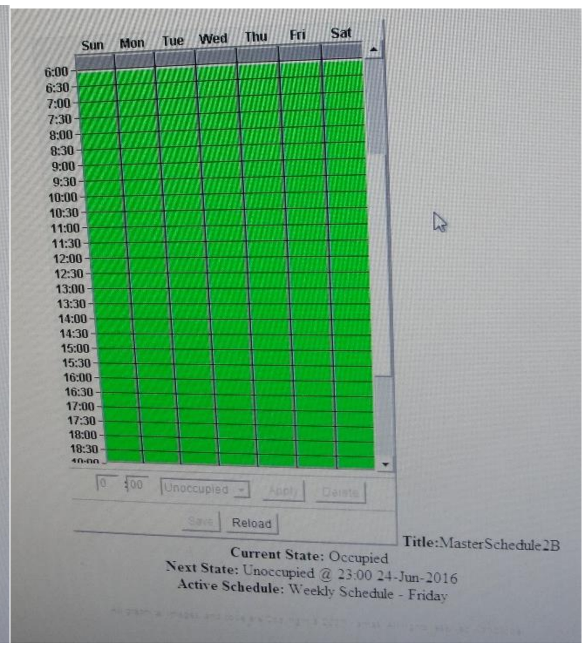
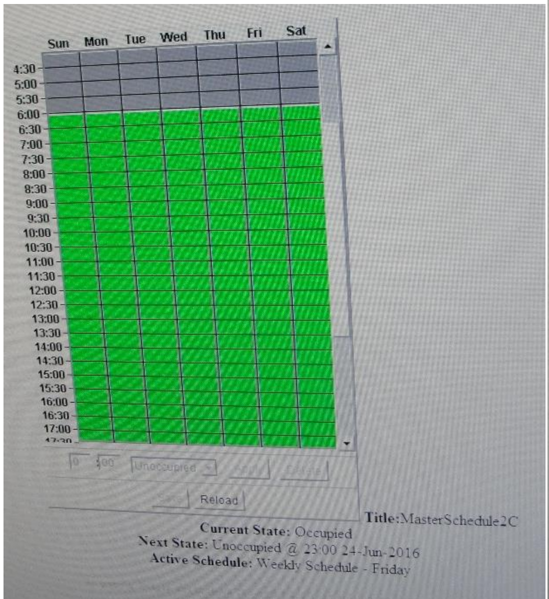
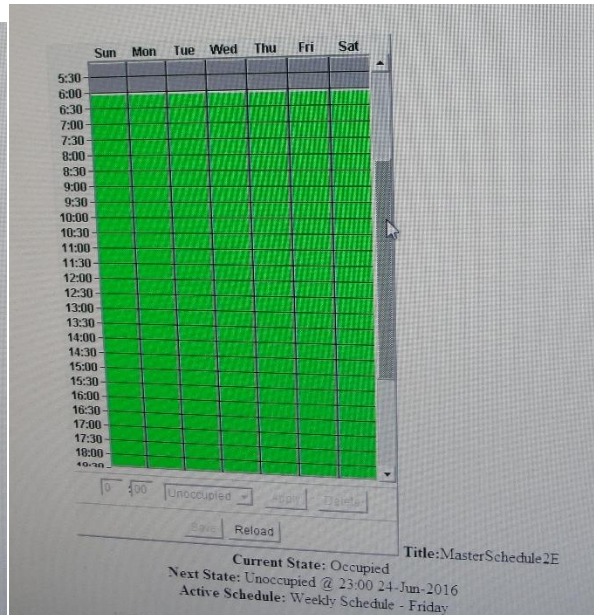
Figure 6. Red Wing Zone 1A Installed Lighting Schedule

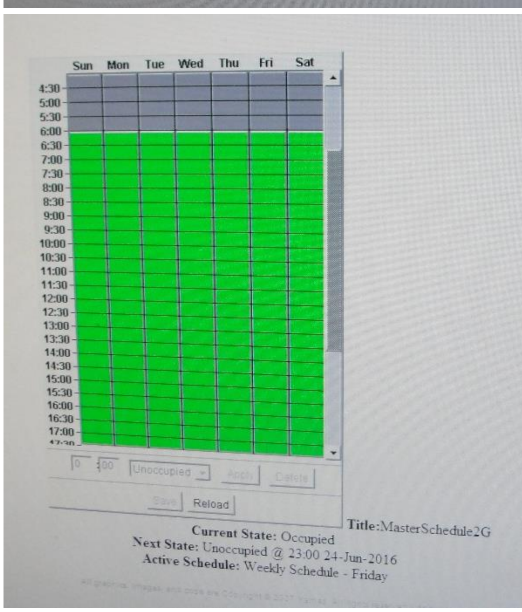


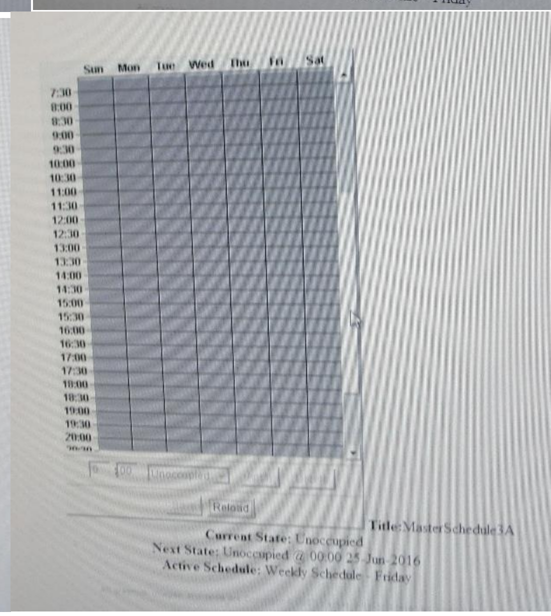












Since the building occupants can override the lighting schedules, Cadmus installed light loggers throughout the facility to collect actual fixture operating hours for a three-week period. Table 5 summarizes fixture quantities and locations of installed light loggers.

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Table 5. Summary of Fixture Counts and Installed Light Loggers

#	Wing	Location	Fixture Description	Light Logger Serial Number
1	Blue	Floor 1 - Outside electrical room	2-lamp, 2’x4' T8	10266124
2		Floor 2 - Outside electrical room	2-lamp, 2’x4' T8	10171838
3		Floor 3 - Outside electrical room	2-lamp, 2’x4' T8	10187474
4	Purple	Floor 3 - Outside electrical room	2-lamp, 2’x4' T8	10261681
5		Floor 2 - Outside electrical room	2-lamp, 2’x4' T8	10346084
6		Floor 1 - Outside electrical room, in corridor to loading dock	2-lamp, 2’x4' T8	10327340

Data Analysis

ECM-1: Relocate 8,760-Hour Lighting Circuits to New Panels with Scheduling

Cadmus extrapolated the emergency lighting fixture counts from the teal wing to the remaining three wings. Based on the teal wing counts, the total installed case emergency fixture count is estimated to be 336, versus 228 fixtures in the original application.

Since Cadmus could not confirm the number of pre-retrofit fixtures on emergency circuits, we assumed that the total pre-retrofit count of 450 in the original application was correct. We assumed that the remaining 114 lighting fixtures were operated 65% of the year (5,709 hours per year) based on the metered data collected for ECM-3 (see Table 6 below). In contrast, the original analysis assumed that the fixtures removed from emergency circuits would operate approximately 3,400 hours per year.

The energy savings and peak demand reduction for this measure (without HVAC interactive effects) are 18,782 kWh and 0.0 kW, respectively.

ECM-2: Replace Parking Lot Photocells with Timeclock Controls

Since it is unclear how long the remote lot will be unused, Cadmus evaluated this measure assuming the timeclock controls were still active. In the pre-retrofit case, the fixtures were on photocell control and operated approximately 4,380 hours per year. In the installed case, the fixtures operated approximately 1,638 hours per year.

The HPS fixture input is 460 watts based on technical reference manual lookup tables. The total connected load is 7.36 kW. The energy savings and peak demand reduction for this measure are 20,181 kWh and 0.0 kW, respectively.

ECM-3: Install New Lighting Control System with Zone Control

Cadmus used the survey and light logger data to verify operating hours for the existing interior lighting fixtures. Table 6 summarizes the light logger data.

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Table 6. Summary of Light Logger Data

Logger #	Wing	Floor	Total Metered Hours	Total Operating Hours	Percentage Operating	Average Coincidence Factor
1	Blue	Floor 2	435.0	220.9	51%	100%
2	Blue	Floor 3	435.0	311.7	72%	100%
3	Purple	Floor 3	434.9	315.4	73%	100%
4	Purple	Floor 2	434.8	311.5	72%	100%
5	Purple	Floor 1	434.7	257.6	59%	100%
Average			**434.9**	**283.4**	**65%**	**100%**

The five loggers produced a mean projected annual runtime of 5,709 hours. During the three-week metering period, the site produced a mean coincidence factor of 100%. Since the occupants can override the programmed schedules, Cadmus used the metered operating hours to evaluate the measure.

The lighting fixtures in the teal wing and third floor of the red wing were also assumed to operate 5,709 hours per year to account for expected future growth.

The fixture input for the two-lamp, 2-foot by 4-foot T8 troffer is 54 watts. The fixture counts in each wing were assumed to equal that submitted in the original application. The evaluated total connected lighting load in the pre-retrofit and installed case was estimated to be 190.4 kW.

Cadmus assumed that the pre-retrofit lighting schedules submitted in the original application were accurate. The pre-retrofit fixtures averaged 5,222 annual operating hours.

The energy savings and peak demand reduction for this measure (without HVAC interactive) effects are -92,689 kWh and 0.0 kW, respectively.

Cadmus also calculated energy savings and demand reductions for interior spaces with HVAC interactive effects, based on the heating and cooling system type we observed on site. Cadmus used the waste heat factors listed in TechMarket Works' Process and Impact Evaluation of the Non-Residential Smart $aver® Prescriptive Program in the Carolina System: Lighting and Occupancy Sensors report submitted in April 2013. The energy waste heat factor for a small office near [redacted], North Carolina with air conditioner cooling, an economizer, and electric heating is -0.032 and the demand factor is 0.136. The following equation is used to calculate savings with HVAC interactions:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$

$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

Where:

WHFe = Waste heat factor for energy (= -0.032)

WHFd = Waste heat factor for demand (= 0.136)

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The total evaluated energy savings for the three measures with HVAC effects were -51,361 kWh. The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 0.00 kW, and the average, or non-coincident, peak demand reduction was -5.86 kW.

Conclusion

The overall energy savings realization ratio was -11%, compared to Duke Energy claimed savings. The summer peak demand realization rate was calculated as 100%. The average (or non-coincident) peak demand reduction realization rate was -15%.

Cadmus identified the following differences from the original application that impacted the evaluated energy savings:

- There are more lighting fixtures on emergency circuits than expected in the original application
- The fixtures that were taken off emergency circuits operate for longer than expected in the original study
- There are fewer HPS fixtures in the remote parking lot than expected in the original application
- The timeclock controls for the remote lot HPS fixtures were scheduled to be on from Monday through Sunday, versus Monday through Friday in the original application
- The installed zone controls have less aggressive schedules than the site's pre-retrofit, single-zone lighting control system (the new controls do not appear to be programmed as expected in the original study)

Table 7 provides a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 8 provides realization rates comparing energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

Table 7. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

ECM	Applicant		Duke Energy Claimed			Evaluation		
	Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	75,730	N/A	69,451	0.00	7.96	18,181	0.00	2.08
2	38,916	N/A	39,533	0.00	0.32	20,181	0.00	2.30
3	385,638	N/A	360,080	0.00	30.83	-89,723	0.00	-10.24
Total	**500,284**	**N/A**	**469,065**	**0.00**	**39.11**	**-51,361**	**0.00**	**-5.86**

Table 8. Energy Savings and Demand Reduction Realization Rates

ECM	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	26%	NA	26%
2	51%	NA	719%
3	-25%	NA	-33%
Total	**-11%**	**NA**	**-15%**

Application ID 15-1806905
Lighting
M&V Report

November 16, 2016

Duke Energy
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.

An Employee-Owned Company • www.cadmusgroup.com

Prepared by:
Dave Korn
Christie Amero

Cadmus

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Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for one retrofit energy conservation measure (ECM) as part of the [redacted], Smart $aver custom incentive program application—specifically for replacing 1,467 fluorescent T12 lighting fixtures with 452 reduced-wattage T8 fixtures. Energy savings were expected to result from the reduced fixture input wattage and the reduced fixture quantity. A description of the measure as submitted in the original application documentation is provided below.

ECM-1: Replace Fluorescent T12 Fixtures with Reduced Wattage T8s

[Redacted] is a manufacturer and distributor of windows treatments and operates a warehouse in [redacted], North Carolina, for 3,120 hours per year, according to the original application.

This retrofit project replaced 797 one-lamp, 8-foot T12 high-bay fixtures and 670 four-lamp, 4-foot T12 fixtures with 204 two-lamp, 4-foot, reduced-wattage T8 troffers and 248 four-lamp, 4-foot, reduced-wattage T8 strip fixtures, respectively. The installed lamps and ballasts were listed on the Consortium for Energy Efficiency's approved equipment list.

The decreased fixture quantity was supported by a lumen-level study performed by the original project engineer; this indicated that an adequate light level would be maintained despite a large reduction in the number of installed fixtures.

Goals and Objectives

Table 1 shows the projected savings goals identified in the project application.

Table 1. Project Goals

Application		Duke Energy			
Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
501,971	N/A	501,971	488,514	160.89	38.38

* Source: DSMore input spreadsheet.

For this M&V project, Cadmus sought to verify actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

Project Contacts

Table 2 lists the Duke Energy contact who granted Cadmus approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

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Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 3.

Table 3. Site Location

Address	ECM
Redacted	1

M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. Christie Amero of Cadmus performed the site visit on June 20, 2016.

Field Survey

During the site visit, Cadmus met with the facility manager and site electrician to review the lighting survey and to collect general operating information. The [redacted] facility is a furniture distribution center composed of administrative offices, a warehouse, and a bulk storage room. According to the facility manager, the warehouse is approximately 124,000 square feet.

The operating hours are Mondays through Thursdays, from 6:00 a.m. to 4:30 p.m., year round. However, the site contact said the lighting fixtures may be turned on as early as 5:15 a.m. The site observes approximately 10 holidays per year.

Conditioning for the administrative offices is provided by Carrier heat pumps. Conditioning for the warehouse is provided by four 40-ton Lennox direct expansion units with electric heating coils. There are two small Trane air conditioning units for the data room. The bulk storage space is heated only by electric unit heaters to 50°F in the winter months.

The facility manager confirmed that all pre-retrofit spaces had T12 fluorescent lamps. No occupancy sensors or daylighting controls were installed as part of the project: all the fixtures are controlled manually. The facility manager said the staff has noticed an improvement in the lighting quality and estimated that the project has reduced their electricity bill by approximately $500 per month.

Field Data

ECM-1: Replace Fluorescent T12 Fixtures with Reduced Wattage T8s

After completing the lighting survey, Cadmus performed a walkthrough of the facility to verify the new lighting fixture types and to install light loggers. Figure 1 and Figure 2 show the four-lamp, 4-foot T8 lighting strip fixtures in the bulk storage space. Figure 3 shows the 32-watt T8 lamp that was installed in the bulk storage fixtures. Cadmus was not able to inspect the ballast for the bulk storage fixtures due to the height of the fixtures. The site contact did not have any extra ballasts for the bulk storage fixtures.

Figure 1. Fluorescent Lighting Fixtures in Bulk Storage Space

Figure 2. 4-Lamp, 4-Foot T8 Fixture in Bulk Storage Space

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Figure 3. 32-Watt T8 Lamp Installed in Bulk Storage Space

Figure 4 shows the two-lamp, 2-foot by 4-foot T8 troffer fixture installed in the warehouse and offices. Figure 5 shows the make and model number of the installed, 28-watt T8 lamp. Figure 6 shows the installed ballast for the warehouse and office fixtures.

Figure 4. 2-Lamp, 2-Foot by 4-Foot T8 Lighting Fixture in Warehouse Space

Figure 5. Reduced Wattage Fluorescent 4-Foot 28-Watt T8 Lamp

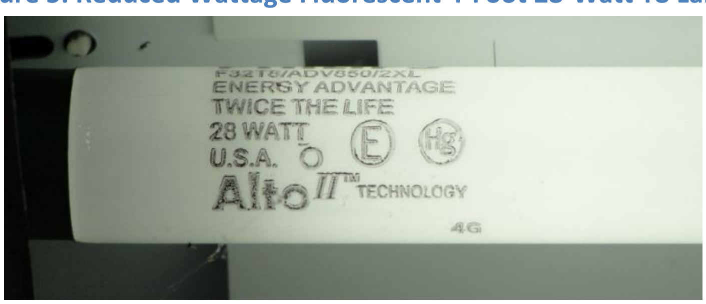

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Figure 6. GE Ballast for 4-Foot, 2-Lamp T8 Fixtures

Cadmus installed light loggers throughout the facility to collect fixture operating hours for a three-week period. Table 4 summarizes the locations of installed light loggers and monitored fixture types.

Table 4. Summary of Fixture Counts and Installed Light Loggers

#	Section	Location	Fixture Description	Light Logger Serial Number
1	Office	Corner fixture near door	2-lamp, 4-foot T8s	10221844
2	Entryway	2nd fixture in from main door	2-lamp, 4-foot T8s	10270023
3	Warehouse	Between section A49 and A48	2-lamp, 4-foot T8s	10268265
4	Bulk Storage	Pole C, row 5	4-lamp, 4-foot T8s	10187339
5	Warehouse Bathroom	Ladies bathroom	2-lamp, 4-foot T8s	10187397

Data Analysis

ECM-1: Replace Fluorescent T12 Fixtures with Reduced Wattage T8s

Cadmus used the survey and light logger data to verify demand and operating hours for the installed lighting fixtures. Table 5 summarizes the light logger data.

Table 5. Summary of Light Logger Data

#	Section	Total Metered Hours	Total Operating Hours	Percentage Operating	Average Coincidence Factor
1	Office	551.1	137.2	25%	50%
2	Entryway	550.8	550.8	100%	100%
3	Warehouse	550.6	147.0	27%	57%
4	Bulk Storage	550.5	144.7	26%	30%
5	Warehouse Bathroom	550.4	550.4	100%	100%

The projected annual operating hours are 2,180 hours for office fixtures, 8,760 hours for the entryway fixtures, 2,339 hours for the warehouse fixtures, and 2,303 hours for the bulk storage fixtures. Cadmus assumed that the operating hours and coincidence factors were equal in the pre-retrofit and installed cases.

Cadmus used the survey data and lamp and ballast model numbers we collected on the site to calculate the actual installed fixture demand (kW). The two-lamp, 2-foot by 4-foot troffer fixtures in the office and warehouse spaces were installed with 28-watt lamps and the overall fixture input is 64 watts according to the GE ballast specifications. Based on the MassSave 2013 rated wattage tables, the four-lamp, 4-foot strip fixtures in the bulk storage spaces were installed with 32-watt T8 lamps and the overall fixture input is 107 watts. Cadmus confirmed the fixture quantities submitted in the original application via an invoice provided by the site contact. The connected lighting load for the installed system is 39.59 kW.

Cadmus confirmed the power usage of pre-retrofit fixtures using technical reference manual lookup tables. A four-lamp, 2-foot by 4-foot troffer fixture with F40 T12 lamps is rated at 160 watts, and a one-lamp, 8-foot strip fixture with F40 T12HO lamps is rated at 125 watts. We confirmed the pre-retrofit fixture quantities using the same invoice described above, which included demolition costs.

The energy savings and peak demand reduction without HVAC interactive effects are 386,361 kWh and 73.70 kW, respectively.

Cadmus also calculated energy savings and demand reductions with HVAC interactive effects for the office and warehouse fixtures, based on the heating and cooling system type we observed on site. Cadmus used the waste heat factors listed in TechMarket Works' Process and Impact Evaluation of the Non-Residential Smart $aver® Prescriptive Program in the Carolina System: Lighting and Occupancy Sensors report submitted in April 2013. The energy waste heat factor for a small office near Charlotte, North Carolina with heat pump cooling and heating and no economizer is 0.047, and the demand factor is 0.152. The energy waste heat factor for a warehouse near Charlotte, North Carolina with air conditioner cooling, electric heating, and no economizer is -0.183, and the demand factor is 0.127. The following equations are used to calculate savings with HVAC interactions:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$

$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

Where:

WHFe = Waste heat factor for energy

WHFd = Waste heat factor for demand

The total evaluated energy savings were 359,800 kWh. The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 80.6 kW, and the average, or non-coincident, peak demand reduction was 41.1 kW.

Conclusion

The overall energy savings realization rate was 74%, compared to Duke Energy claimed savings. The summer peak demand realization rate was calculated as 50%. The average (or non-coincident) peak demand reduction realization rate was 107%.

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Cadmus found a slight variation in the installed lighting fixture wattage compared to the original application. The T8 lamps installed in the bulk storage areas are 32 watt, versus 28 watts as outlined the original study. The T8 lamps installed in the offices and warehouse are 28 watts, as expected.

The most significant impact on the evaluated energy savings and peak demand reduction was that the evaluated annual operating hours were 26% less than that claimed in the original application. The evaluated average peak coincidence factor was 43%, versus 100% claimed in the original application.

Table 6 provides a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 7 provides realization rates comparing energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

Table 6. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
501,971	N/A	488,514	160.89	38.38	359,800	80.6	41.1

Table 7. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
74%	50%	107%

Application ID 13-1464614 Lighting Replacement M&V Report

August 5, 2016

Duke Energy Carolinas
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Introduction

This report addresses M&V activities for lighting retrofit energy conservation measures (ECMs), conducted as part of the [redacted] Smart $aver custom incentive program application; specifically, the replacement of fluorescent lighting fixtures with LED fixtures.

ECMs—Replace Fluorescent Lighting Fixtures with LED Lighting Fixtures

These measures involve replacing 3,268 fluorescent T8 and T12 fixtures with LED fixtures. Table 1 summarizes pre-retrofit and installed lighting fixtures.

Table 1. Summary of Pre-Retrofit and Installed Lighting Fixtures

ECM	Fixture Quantity	Area Served	Pre-Retrofit		Installed	
			Fixture Description	W / Fixture	Fixture Description	W / Fixture
1	64	Manufacturing	2LT12 troffer	631	LED	280
2	90	Manufacturing	2LT12 strip	631	LED	350
3	245	Manufacturing	2LT8 strip	508	LED	350
4	50	Manufacturing	3LT8 troffer	710	LED	499
5	1,569	Manufacturing	4LT12 troffer	1,261	LED	499
6	542	Offices	4LT12 troffer	374	LED	148
7	85	Manufacturing	4LT8 troffer	937	LED	499
8	61	Manufacturing	1LT12 strip	604	LED	350
9	1	Manufacturing	2LT12 strip	1,077	LED	701
10	12	Manufacturing	2LT8 strip	508	LED	350
11	1	Manufacturing	4LT12 strip	2,155	LED	701
12	1	Manufacturing	4LT8 strip	937	LED	701
13	516	Manufacturing	8' 1LT12	981	LED	350
14	1	Manufacturing	8' 2LT12	1,989	LED	701
15	30	Manufacturing	4' 2LT12	631	LED	350
Total	**3,268**					

Goals and Objectives

Table 2 shows the projected savings goals identified in the project application. Duke Energy did not provide a breakdown of claimed savings by measure.

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Table 2. Project Goals

ECM	Applicant		Duke Energy			
	Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1	15,768	1.8	22,426	N/A	N/A	N/A
2	25,229	2.9	24,645	N/A	N/A	N/A
3	38,632	4.4	37,043	N/A	N/A	N/A
4	10,512	1.2	18,243	N/A	N/A	N/A
5	1,166,044	133.1	1,438,356	N/A	N/A	N/A
6	122,600	47.2	147,473	N/A	N/A	N/A
7	37,230	4.3	50,372	N/A	N/A	N/A
8	12,448	1.4	15,496	N/A	N/A	N/A
9	84,376	9.6	108,387	N/A	N/A	N/A
10	1,892	0.2	1,814	N/A	N/A	N/A
11	82,887	9.5	82,148	N/A	N/A	N/A
12	12,299	1.4	11,625	N/A	N/A	N/A
13	293,916	33.6	322,107	N/A	N/A	N/A
14	504,786	57.6	550,694	N/A	N/A	N/A
15	2,803	0.3	8,215	N/A	N/A	N/A
Total	**2,411,422**	**308.4**	**2,839,044**	**2,812,619**	**361.4**	**361.3**

* Source: DSMore input spreadsheet.

The M&V project sought to verify the actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization rates (kW and kWh)

Project Contacts

The Duke Energy contact listed in Table 3 granted approval to plan and to schedule the site visit for this M&V effort.

Table 3. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Frankie Diersing	office: 513-287-4096 frankie.diersing@duke-energy.com
Cadmus	Christie Amero	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

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Site Location

The location where these measures were installed is shown in Table 5.

Table 4. Project Location

Address	ECMs
redacted	1-15

M&V Option

To assess this project, Cadmus utilized IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit, which Tom Davis of Cadmus performed on January 5, 2016.

Field Notes

During the site visit, Cadmus photographed fixture information, conducted a survey with facility personnel, and installed lighting loggers. The facilities operates seven days per week, without controls, and its schedule did not change after installation.

Field Data

Cadmus installed 15 light loggers to meter the facility for two weeks, and then used these data to estimate annual hours of operation. Table 5 summarizes the light logger data.

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Table 5. Summary of Meter Data

Meter S/N	Location	Metered Hours	Operating Hours	Percentage Operating	Projected Annual Operating Hours	Coincidence Factor
10380417	Supply	322	93	29%	2,539	17%
10380535	Warehouse walkway	322	322	100%	8,760	100%
10380565	Office #1181	322	85	27%	2,325	11%
10380571	Lunch/break	322	322	100%	8,760	100%
10380601	Inspection #1703	322	322	100%	8,760	100%
10380602	Office #1183	322	87	27%	2,355	12%
10380608	Office #1101	322	111	35%	3,031	28%
10380618	Front office hallway	322	169	52%	4,595	71%
10380619	Hallway, warehouse	322	322	100%	8,760	100%
10374182	Blending/discharge #1510	322	322	100%	8,760	100%
10374185	Staging - main warehouse floor	322	322	100%	8,760	100%
10374187	Facility maintenance	322	162	50%	4,407	60%
10374188	Kitchen - front offices #2100	322	91	28%	2,472	28%
10380393	Conference #1163	322	37	11%	995	7%
10380402	HR lobby	322	322	100%	8,760	100%

Data Analysis

In its application, [redacted] claimed 8,760 annual hours of operation for ECMs in its warehouse and 2,600 hours for ECMs in its offices. Cadmus averaged the projected annual hours of operation, determined by light loggers installed in these spaces, and applied the resulting estimates to calculate savings. On average, lights in the warehouse were projected to operate 8,760 hours annually and lights in offices were projected to operate 4,024 annually. These values were applied to demand values and quantities confirmed on site to calculate savings, as shown in Table 6. Additionally, Cadmus averaged peak coincidence factors for each space type and used these values to calculate peak demand reductions and applied waste heat factors to final numbers to account for HVAC interactive effects.

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Table 6. Savings Calculations

ECM	Qty	Annual Operating Hours	CF	Pre-Retrofit kW	Installed kW	Energy Savings		
						Avg. kW Reduction	CP kW Reduction	Annual kWh
1	64	8,760	100%	0.07	0.03	2.56	2.56	22,426
2	90	8,760	100%	0.07	0.04	2.81	2.81	24,645
3	245	8,760	100%	0.06	0.04	4.23	4.23	37,043
4	50	8,760	100%	0.08	0.04	2.08	2.08	18,243
5	1,569	8,760	100%	0.14	0.04	164.20	164.20	1,438,356
6	542	4,024	43%	0.14	0.04	56.72	24.39	228,242
7	85	8,760	100%	0.11	0.04	5.75	5.75	50,372
8	61	8,760	100%	0.07	0.04	1.77	1.77	15,496
9	1	8,760	100%	36.65	24.28	12.37	12.37	108,387
10	12	8,760	100%	0.06	0.04	0.21	0.21	1,814
11	1	8,760	100%	14.02	4.64	9.38	9.38	82,148
12	1	8,760	100%	5.56	4.24	1.33	1.33	11,625
13	516	8,760	100%	0.11	0.04	36.77	36.77	322,107
14	1	8,760	100%	98.06	35.20	62.86	62.86	550,694
15	30	8,760	100%	0.07	0.04	0.94	0.94	8,215
Total			**-**	**155.3**	**68.8**	**437.9**	**399.0**	**3,188,437**

Conclusion

Cadmus found the measures and quantities installed as expected. The energy savings realization rate is 113%, compared to Duke Energy claimed savings, due to of greater usage in office spaces than initially reported. The summer coincident peak demand realization rate is calculated at 110%, given 43% peak coincidence factor measures installed in office spaces. The noncoincident peak demand reduction realization rate is 121%.

Table 7 provides a comparison of the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction. Table 8 provides the realization rates compared to energy savings and demand reductions claimed by Duke Energy.

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Table 7. Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Avg. kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
2,411,422	308.4	2,812,619	361.4	361.3	3,188,437	399.0	437.9

Table 8. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW	Non-CP kW
113%	110%	121%

Application ID 12-296
Injection Molding Machine Retrofit
M&V Report

Prepared for
Duke Energy South Carolina

February 2015, Version 3.0
(revised August 19, 2016)

This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and program

Submitted by:

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Stuart Waterbury
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2540 Frontier Avenue, Suite 100
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80301

(303) 444-4149

On August 19, 2016 the Duke Energy projected savings in this report were corrected by Cadmus to correspond to Duke Energy expected savings as found in the Duke Energy program tracking database.

Introduction

This document addresses M&V activities for the injection molding machine retrofit for [redacted] that was rebated under Duke Energy's Smart $aver Custom Incentive program.

ECM-1 – Injection Molding Machine Replacement
[Redacted] is engaged in the manufacture of injection molding products. Injection molding machines – also known as presses – are used to mold polypropylene resin into various exterior building products. These presses range in size from 44-ton to 3000-ton. This project targeted a 1970s vintage 700-ton press that was fully utilized. The old press was replaced with a 2012 model Milacron press that is more energy efficient and was expected to increase productivity.

The old machine had an estimated cycle time of 60 seconds and power usage of 83 kWh/h. The new equipment was estimated to have a cycle time of 32 seconds, power usage of 36 kWh/h and an expected runtime from 7:00am to 7:48pm, 52 weeks per year. Analysis of these metrics is detailed in this report.

Goals and Objectives

A post-retrofit survey of the injection molding machine was conducted to determine the power reduction from the upgrade.

The projected savings goals were:

Application Proposed Annual savings (kWh)	Application Proposed Peak Savings (kW)	Duke Expected Savings (kWh)	Duke Expected Peak Savings (kW)
398,112	47	402,674	48

The objective of this M&V project was to verify the actual:

- Average pre/post load shapes by daytype for controlled equipment
- Facility peak demand (kW) savings
- Summer utility coincident peak demand (kW) savings
- Annual energy (kWh) savings

Project Contacts

Duke Energy M&V Admin.	Frankie Diersing	513-287-4096	
Site Contact	redacted		
NORESCO Contact	Rob Slowinski	303-459-7409	rslowinski@noresco.com

Site Locations/ECMs

Address	ECMs Implemented
redacted	1

Data Products and Project Output

- Average pre/post load shapes by daytype for controlled equipment
- Facility peak demand (kW) savings
- Summer utility coincident peak demand (kW) savings
- Annual energy (kWh) savings
- kWh & kW Realization Rates

M&V Option

IPMVP Option A

Field Data Points

Post-Installation

Survey data

- Verified that the injection molding machine nameplate data was consistent with the application
- Verified that the old injection molding machine was removed
- The site contact said that the injection molding machine runs 24/7, and produces 1,743 pieces per day.

Field Data Logging

Dual ElitePro data loggers (with 3 Magnelab CTs each) were used to measure the kW of the injection molding machine. One logger was used to gather kW at 1-second increments for 3 days, while the other was used to gather 5-minute data for a period of 3 weeks. Both of these data streams were used to create an accurate characterization of the injection molding machine's load profile.

Data Analysis

Energy savings for this retrofit measure depend upon three major components: the cycle time for the machine, the operational kW of the machine and its use profile throughout the year. To determine the use profile, three weeks of 5-minute interval kW data was logged on the injection molding machine, seen in Figure 1:

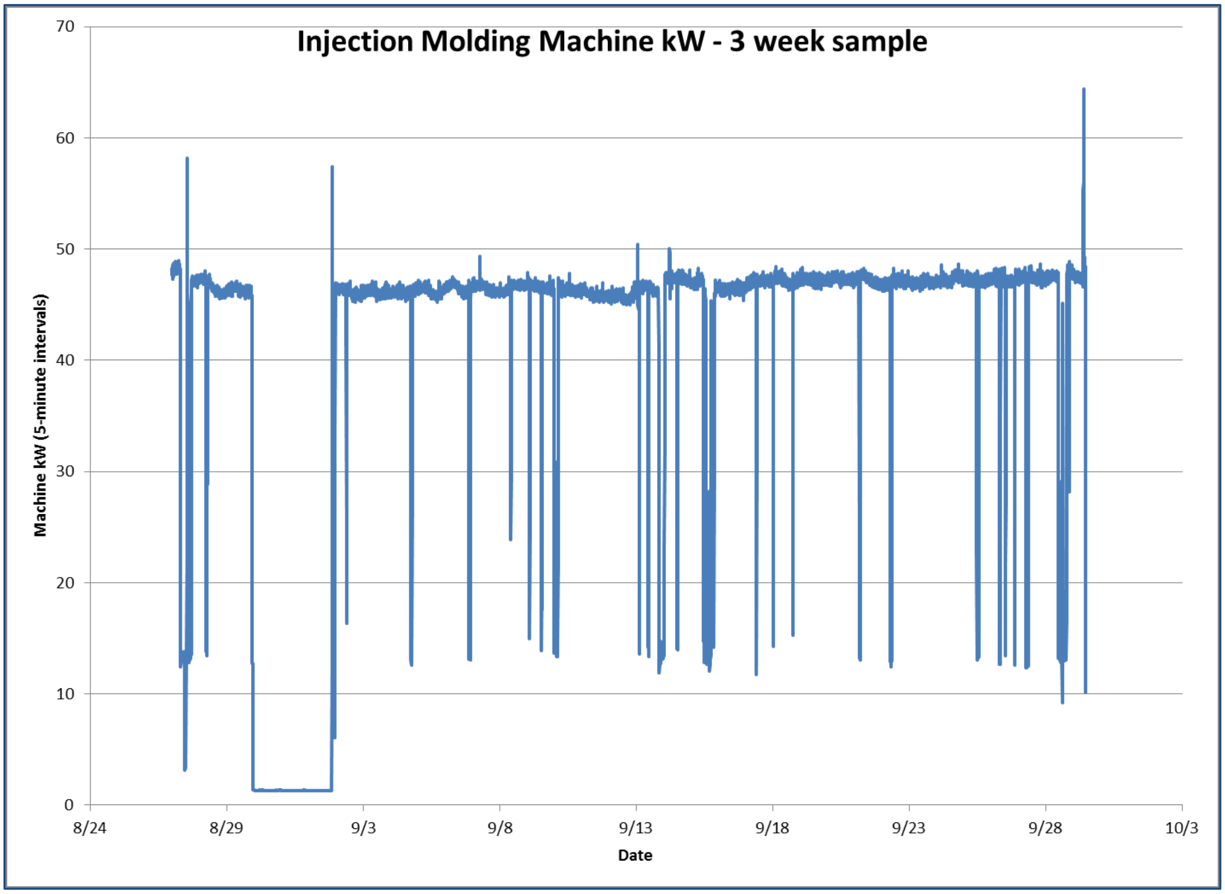

Figure 1: Injection molding machine 3-week usage profile.

The building operator claimed that the machine runs 24/7, save for outages or changeovers, and this is believable, according to the graphed 5-minute interval data. The calculated annual equivalent full load run hours (EFLH)—based on the 3 week data sample—was determined to be 7,684 hours per year.

To determine cycle time, additional data loggers were deployed to capture machine kW at 1-second intervals. This data can be seen in Figure 2.

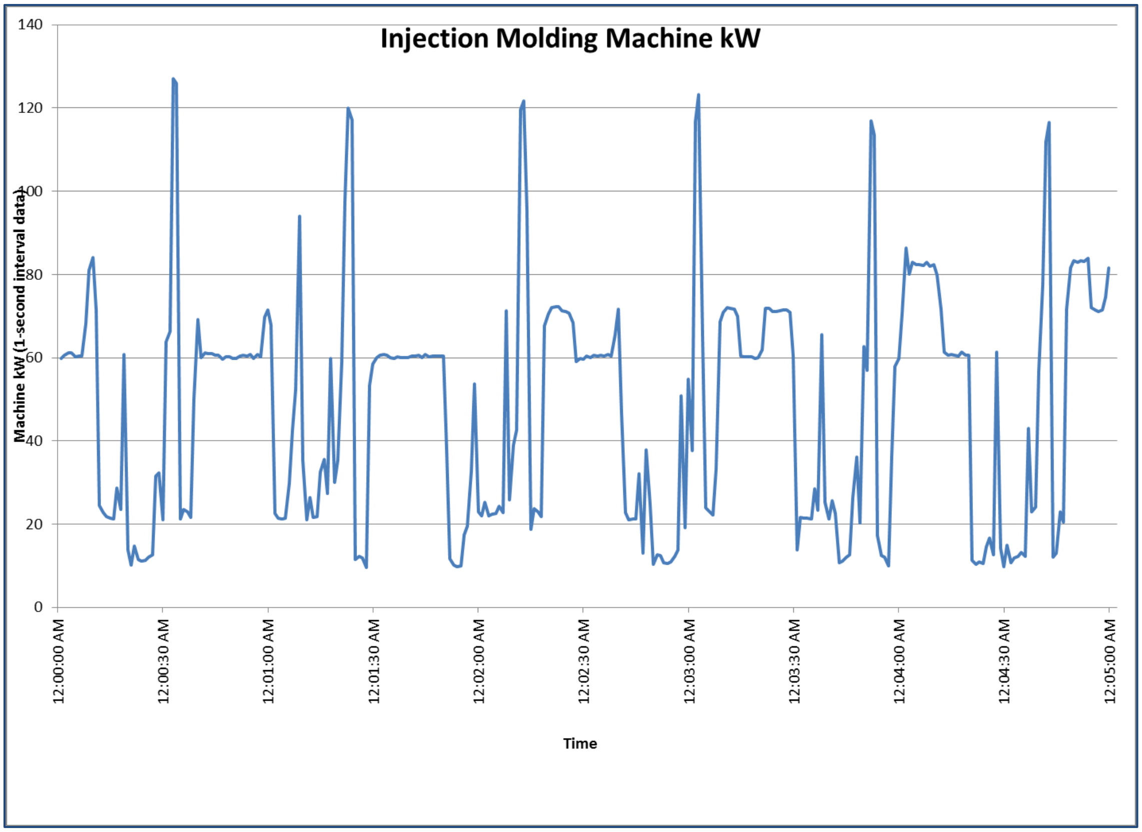

Figure 2: 1-second interval data of machine kW.

Taking a consistent subset of the 1-second interval data, a sample of 25 cycles revealed a cycle time of 49.8 seconds, which amounts to 1,735 cycles per day. The building operator survey revealed a production rate of 1,743 cycles per day (49.6 seconds per cycle), which is very similar. These calculations will use the operator-provided numbers for cycles per day and seconds per cycle.

Finally, calculations revealed that the average operating kW for the injection molding machine (discounting the short downtime seen in the 5-minute data) was 46.7kW.

The energy usage of the machine was then estimated according to the following equation:

$$kWh = \#Cycles \times CycleTime \times \frac{1\ hour}{3600\ seconds} \times OperatingkW$$

where:
Cycles is the annual count of cycles, in this case 558,056 for one year of post-retrofit production
CycleTime is listed in seconds per cycle
OperatingkW is the average kW of the machine during production only.

Rather than using different pre- and post-retrofit throughput levels, the savings calculations normalize the annual throughput. This reflects the reality of the situation, where [redacted] is using the new machine to provide more throughput for the year, rather than simply yield the same amount of throughput in a shorter amount of time. The annual cycles (units produced) per year with the post-retrofit equipment is estimated to be 558,056. In the post-retrofit case, this takes 7,684 hours at full load, while in the pre-retrofit case the production of this many units would theoretically take 9,301 hours.

Verification and Quality Control

1. Visually inspected logger data for consistent operation.
2. Verified the post retrofit machine was consistent with the application.
3. Verified that pre-retrofit machine was removed from the project.

Recording and Data Exchange Format

1. Post-installation Survey Form and Notes.
2. ElitePro logger files
3. Excel spreadsheets

Results Summary

The following tables summarize the total estimated savings for the [redacted] injection molding machine retrofit, both in annual totals and on a per-unit basis.

Table 1. Pre- and Post-Retrofit Energy and Demand Summary.

	Pre-retrofit	Post-retrofit	Savings
Operating Hours	9,301*	7,684	-
Averaged Demand (kW)	83	46.7	36.3
Annual Energy (kWh/year)	771,977	359,156	412,822
Energy per unit produced (kWh/unit)	1.38	0.64	0.74

*Note: The pre-retrofit case involves the hypothetical production of 558,056 units, which would take longer than one year at full load.

Table 2. Annual Energy Savings and Realization Rates.

	Duke Savings	Verified Savings	Realization Rates
Energy (kWh)	402,674	412,822	103%
Peak Demand (kW)	36	36.3	101%
CP Demand (kW)	48	36.3	76%

The energy savings verified by this M&V project are very close to the Duke estimated savings, while peak coincident demand savings fall short of the estimate. This is due to the fact that the machine's operating kW was originally estimated to be 36kW, but logger data shows it to be 46.7kW.

Application ID 14-1785194 Air Compressor Retrofit: M&V Report

August 5, 2016

Duke Energy Carolina
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.

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CADMUS

Prepared by:

Dave Korn

Christie Amero

Cadmus

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Introduction

This report addresses M&V activities for one retrofit energy conservation measure (ECM), conducted as part of the [redacted] Smart $aver custom incentive program application; specifically, the replacement of fixed-speed air compressors with one VFD-driven air compressor.

The following facility and equipment descriptions have based on original project documentation.

ECM-1—VFD Air Compressor

Pre-retrofit: The pre-retrofit case was two 50-hp fixed-speed air compressors and one 25-hp fixed-speed air compressor. The two 50-hp compressors were estimated to operate 7,664 hours per year. The 25-hp compressor served as a trim machine. The site's compressed airflow demand ranged from ~130 cfm to 300 cfm.

Installed: The installed case is one Ingersoll Rand R75N-A115, 100-hp variable-speed, rotary air compressor. Operating hours and compressed airflow demand were assumed to equal the pre-retrofit case.

Goals and Objectives

Table 1 shows projected savings goals identified in the project application.

Table 1. Project Goals

Applicant		Duke Energy			
Annual kWh Savings	Avg. Demand Reduction, kW	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
130,982	15	143,875	142,073	21	21

* Source: DSMore Input spreadsheet.

The M&V project sought to verify the actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization rates (kW and kWh)

Project Contacts

The Duke Energy contact listed in Table 2 granted approval to plan and to schedule the site visit for this M&V effort.

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Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Frankie Diersing	office: 513-287-4096 Frankie.diersing@duke-energy.com
Cadmus	Christie Amero	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The location where this measure was installed is shown in Table 4.

Table 3. Project Location

Address	ECM
redacted	1

M&V Option

To assess this project, Cadmus utilized IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. The site contact confirmed that the equipment was served by 480V and metering could be performed de-energized. The contact confirmed that the site did not have trend points set up on the compressed air system. Christie Amero and Tom Davis of Cadmus performed the site visit on January 7, 2016.

Field Notes

During the site visit, Cadmus met with the site contact to review the metering plan and to collect general operating information.

The site's compressed air system serves paper corrugators on the manufacturing floor. The compressed air system typically operates 24 hours per day, Monday through Friday, and occasionally on Saturdays (depending on production schedules). Separate shifts do not operate during the day, but compressed air demand peaks during cleanup hours.

Production remains fairly consistent throughout the year, and major changes have not occurred to production levels since the project implementation. The contact said the site has added eight stations to the floor, but the compressed air used by the new stations requires a very small percentage of overall use. The compressed air discharge pressure is maintained at 110 psi.

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The new VFD air compressor was installed on May 4, 2015, and has run ~5,900 hours since then. No issues have arisen with the new machine. The two existing, single-stage, 50-hp air compressors remain on site (though are used only as backups).

The new compressor installation included a heat recovery duct to use waste heat for warehouse space heating when outside air conditions permit. During the site visit, the discharge temperature of the compressor ranged between 183°F and 192°F.

Field Data

Table 4 shows data Cadmus collected for the installed VFD air compressor.

Table 4. Equipment Nameplate Data

Equipment ID	Make	Model Number	Serial Number	hp	Control Strategy
VFD Compressor	Ingersoll Rand	R75N-A	NK2265U15043	100	Variable speed

During the site visit, Cadmus photographed the installed and existing air compressors and the associated nameplates. Figure 1 shows the installed VFD compressor. **Error! Reference source not found.** shows the compressor nameplate. Figure 3 shows the compressor's control panel output with the current discharge pressure setpoint and compressor percent capacity. Figure 4 shows the compressor's heat recovery ductwork.

Figure 1. Installed VFD Air Compressor

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Figure 2. VFD Air Compressor Nameplate

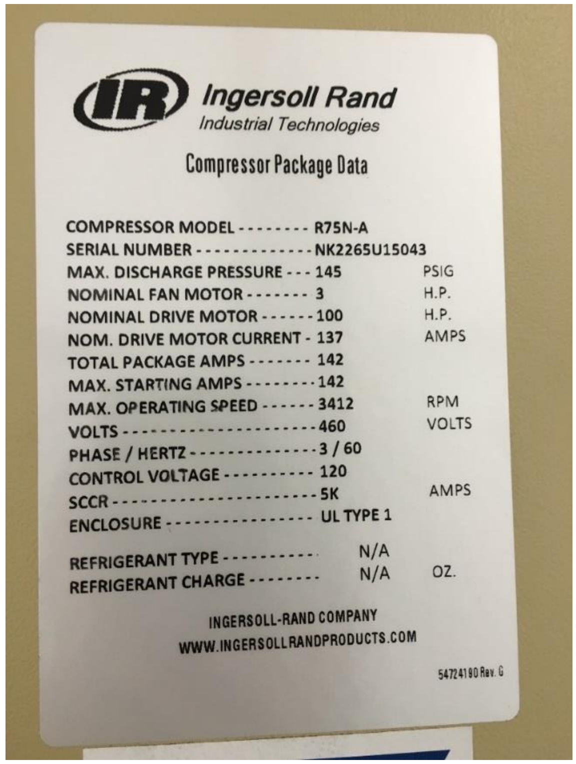

Figure 3. VFD Air Compressor Control Panel—Pressure and % Capacity

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Figure 4. Installed Air Compressor Heat Recovery Duct

Figure 5 documents the old Ingersoll Rand air compressors, which serve only as backups.

Figure 5. Old Ingersoll Rand Single-Speed Compressors—Backups Only

Cadmus installed a three-phase electric power meter on the new VFD air compressor. Data were collected for two weeks at one-minute intervals. Table 5 summarizes the installed metering equipment.

Table 5. Summary of Installed Metering Equipment

Equipment ID	RX3000	WattNode 3D-480	Current Transducers (Qty/Size)
VFD Comp	1	1	3 / 100 A

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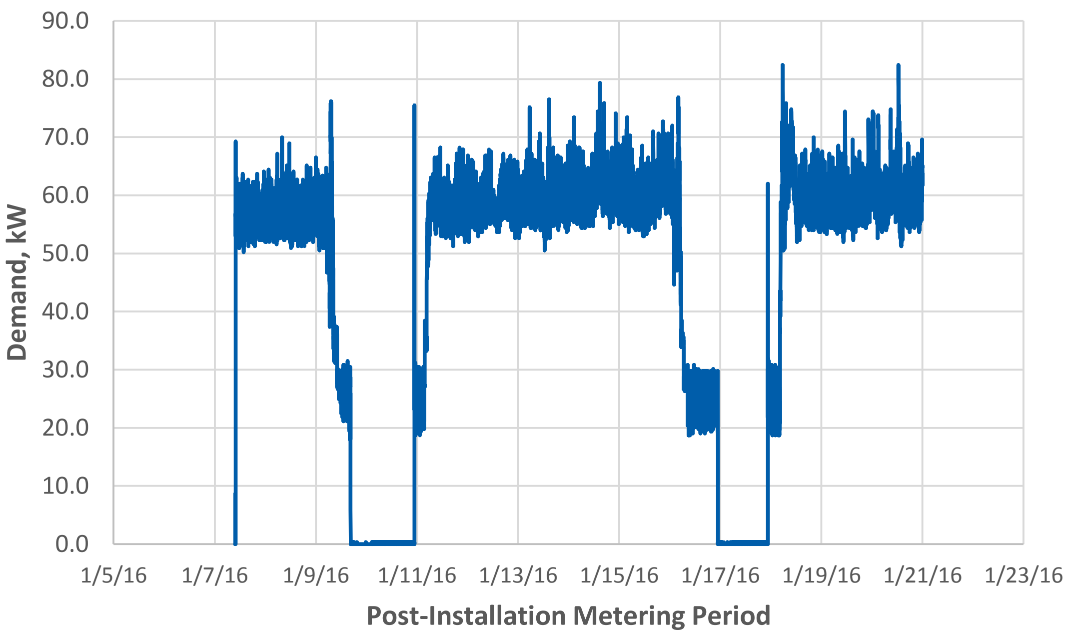
Figure 6 shows the power meter installation, and Figure 7 summarizes the metered demand data for the VFD air compressor during the metering period.

Figure 6. VFD Air Compressor Power Disconnect

Figure 7. VFD Air Compressor Power Metered Data



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Data Accuracy

Table 6. Metering Equipment Accuracy

Measurement	Sensor	Accuracy	Notes
Demand, kW	WattNode Power Meter	±1%	-
Current, amps	Magnelab CT	±1%	Recorded load must be < 130% and > 10% of CT rating

Data Analysis

Cadmus used the post-installation metered data to verify the power demand and operating hours of the controlled equipment. Daily average operating demand and operating hours were averaged per week. The average weekly ratio of operating hours to total hours (including weekends) was 84%, and the average operating demand was 49.9 kW. Based on discussions with site personnel, it was assumed the compressor operates 51 weeks per year (including shutdowns and maintenance).

Evaluated installed case energy use was calculated as 358,527 kWh, with average demand of 40.9 kW, and summer peak coincident demand of 57.3 kW.

As trends could not be obtained for pressure and airflow, Cadmus used airflow data collected in the original study and the assumed compressor performance to calculate pre-retrofit energy use. Average pre-retrofit compressor performance was 0.27 kW/cfm, and average annual airflow demand was 250 cfm. Peak period airflow demand was 286 cfm. Operating hours were assumed equal to the installed case.

Evaluated pre-retrofit energy use is 481,779 kWh, with average demand of 55.0 kW, and summer peak coincident demand of 76.6 kW.

Total evaluated annual energy savings are 123,252 kWh. Evaluated total summer coincident peak demand reduction (July, Monday–Friday, 4:00–5:00 p.m.) is 19.4 kW, and the average (or noncoincident) peak demand reduction is 14.1 kW.

Conclusion

Cadmus found the new VFD air compressor installed as expected. Installation of the heat recovery duct provides additional energy savings, not accounted for in the original analysis.

The overall energy savings realization rate was 87%, compared to the Duke Energy claimed savings. The summer peak demand realization rate was calculated at be 93%. The average demand reduction realization rate was 67%.

Average metered demand data for the compressor fell within 1% of the average demand estimated in the original study. Based on metered data and discussions with site personnel, however, operating hours were projected at 6.3% less (479 hours) than originally expected.

Table 7 provides a comparison of the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction. Table 8 provides the realization rates compared to energy savings and demand reductions claimed by Duke Energy.

Table 7. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Avg. kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
130,982	15	142,073	21	21	123,252	19.4	14.1

Table 8. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
87%	93%	67%

Application ID 13-1624545
HVAC
M&V Report

January 25, 2017

Duke Energy
139 East Fourth Street
Cincinnati, OH 45201

The Cadmus Group, Inc.

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Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for one new construction energy conservation measure (ECM) as part of the [redacted], Smart $aver custom incentive program application—specifically for the installation of a new, high-performance HVAC system for a new data center in [redacted], North Carolina. Energy savings were expected to result from the improved cooling performance and reduced pump and fan demand. A description of the measure as submitted in the original application documentation is provided below.

ECM-1: High-Performance HVAC System

[redacted] Data Centers offers mission-critical data storage and has a campus in [redacted], North Carolina. In 2014, it constructed a new 75,700 square-foot data center, referred to as Project Hawk. The data centers operate 24 hours per day, year round, and require year-round cooling to maintain space conditions for data storage equipment.

Baseline: This project's baseline was determined using the Pacific Gas & Electric Energy Efficiency Baseline for Data Centers document (dated November 30, 2011). In 2011, variable-speed motors and water-side economizers were not considered baseline designs for data centers.

Installed: This project entailed installing an energy-efficient HVAC system for the new data center, which included variable-speed centrifugal chillers, variable-speed pumps and cooling tower fans, and a waterside economizer to provide free-cooling for the data center when outside air conditions allowed. A summary of the installed equipment follows:

- Four York YKC3CRQ4-EGGS, 280-ton, variable-speed centrifugal chillers
- Four BAC PG-S3000/3436C, cross-flow cooling towers, each with a 30-hp variable-speed fan motor
- One Alfa Laval MX25M-FGS, 840-ton, plate and frame heat exchanger
- Four 25-hp variable-speed chilled water pumps
- Four 25-hp variable-speed condenser water pumps

In the original analysis, energy savings were calculated using an eQuest software energy model, employing typical meteorological year (TMY) data for Charlotte, North Carolina. Envelope, lighting, and other interior parameters were added, based on facility design documents. The eQuest total design cooling load was 746 tons.

Goals and Objectives

Table 1 shows the projected savings goals identified in the project application.

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Table 1. Project Goals

Application		Duke Energy			
Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
2,914,790	N/A	2,914,790	2,914,790	233.67	253.20

* Source: DSMore input spreadsheet.

The objectives of this M&V project were to verify the following actual data:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

Project Contacts

Table 2 lists the Duke Energy contact who granted Cadmus approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

Table 2. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 3.

Table 3. Site Location

Address	ECM
redacted	1

M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy, seeking to review the evaluation plan and schedule the site visit. During the initial discussion with the site contact, Cadmus was informed that the EMS for the chilled water system currently trends power and energy use on all controlled

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equipment, and therefore that additional on-site power metering would not be necessary. Cadmus sent a list of required trends to the site contact ahead of the site visit. Christie Amero of Cadmus performed the site visit on June 21, 2016, to physically verify the installed equipment and collect the trend data.

Field Survey

During the site visit, Cadmus met with the facility manager to review the lighting survey and to collect general operating information. The Project Hawk site provides redundant customer data storage for emergency situations. The data center equipment is mission critical and operates 24 hours per day, year round. The data center uses cold aisle containment for the racks.

The site is still in the process of building out the data racks and increasing the cooling load. According to the facility manager, the site does not expect to reach capacity for five to seven years. The load had remained fairly constant over the past year and the facility manager did not expect the load to increase significantly over the coming year.

Field Data

ECM-1: High-Performance HVAC System

Cadmus collected the data shown in Table 4 for all installed equipment included in the application.

Table 4. Installed Equipment Nameplate Data

Equipment Type	ID	Make	Model Number	S/N	Size
Chillers	CH-1A	York	YKC3CRQ4/VSD351	KVM-060	280 tons
	CH-1B	York	YKC3CRQ4/VSD351	KVM-049	280 tons
	CH-2A	York	YKC3CRQ4/VSD351	KVM-027	280 tons
	CH-2B	York	YKC3CRQ4/VSD351	KVM-047	280 tons
Condenser Water Pumps	CWP-1A	Baldor	EM2531T-C	40E246/793C1	25 hp
	CWP-1B	Baldor	EM2531T-C	40E246/793C1	25 hp
	CWP-2A	Baldor	EM2531T-C	40E246/793C1	25 hp
	CWP-2B	Baldor	EM2531T-C	40E246/793C1	25 hp
Chilled Water Pumps	CHWP-1A	Baldor	EM2515T-G	39E366W915G1	20 hp
	CHWP-1B	Baldor	EM2515T-G	39E366W915G1	20 hp
	CHWP-2A	Baldor	EM2515T-G	39E366W915G1	20 hp
	CHWP-2B	Baldor	EM2515T-G	39E366W915G1	20 hp
Cooling Towers	CT-1A	BAC	PG S3000/3436C-4	N/A	30 hp
	CT-1B	BAC	PG S3000/3436C-4	N/A	30 hp
	CT-2A	BAC	PG S3000/3436C-4	N/A	30 hp
	CT-2B	BAC	PG S3000/3436C-4	N/A	30 hp
Heat Exchanger	PFHX-1	Alfa Laval	MX25M-FG	N/A	840 tons

During the site visit, Cadmus photographed the chilled water plant equipment and nameplates: Figure 1 shows one of the York variable speed chillers and the variable speed drive (VFD) nameplate; Figure 2 shows a chiller control panel; and Figure 3 shows one of the Baltimore Aircoil cooling towers and the VFD panel for CT-2B.

Figure 1. Variable Speed Chiller and VFD Nameplate

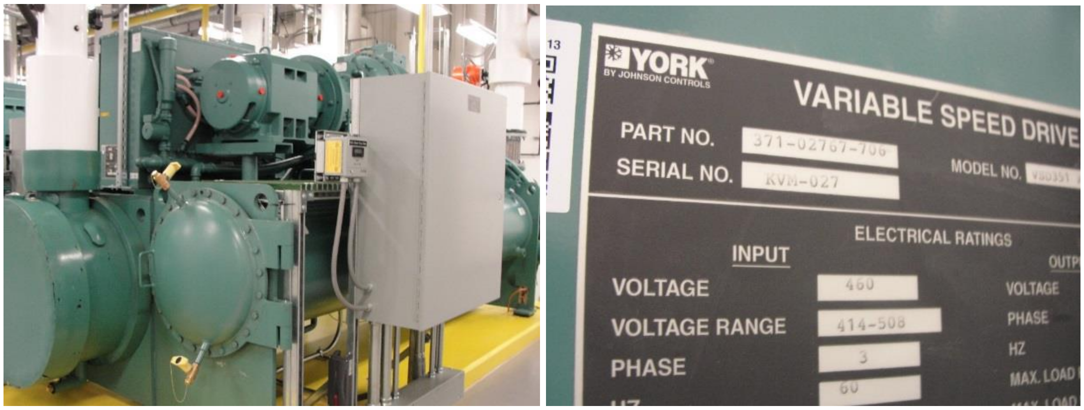

Figure 2. Variable Speed Chiller Control Panel

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Figure 3. Cooling Tower and Drive for CT-2B

Figure 4 shows one of the chilled water pump VFDs and the motor nameplate. Figure 5 shows one of the VFDs for a condenser water pump and the pump motor nameplate.

Figure 4. Chilled Water Pump VFD and Motor Nameplate

Figure 5. Condenser Water Pump (CWP-1B) VFD and Motor Nameplate

Figure 6 shows the plate and frame heat exchanger used to provide free-cooling.

Figure 6. Plate and Frame Heat Exchanger

Cadmus also collected trended power demand data for all equipment submitted in the application. Table 5 summarizes the trend points that were collected.

Table 5. Trend Points Collected from Site

Equipment ID	Trend Point	Interval	Duration
Chillers (CH-1, 2, 3, & 4)	Flow rate, GPM	1 minute	1 year
	Supply temperature, °F	5 minutes	1 year
	Return temperature, °F	5 minutes	1 year
	Total, kW	5 minutes	1 year
Chilled Water Pumps (CHWP-1, 2, 3, & 4)	Pump motor VFD speed, Hz	5 minutes	1 year
	Pump output, kW	5 minutes	1 year
Condenser Water Pumps (CWP-1, 2, 3, & 4)	Pump motor VFD speed, Hz	5 minutes	1 year
	Pump output, kW	5 minutes	1 year
Cooling Towers (CT-1, 2, 3, & 4)	Fan motor VFD speed, Hz	5 minutes	1 year
	Fan output, kW	5 minutes	1 year
Outside Air Conditions	Wet bulb temperature, °F	1 minute	6 months
	Dry bulb temperature, °F	1 minute	6 months

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Data Analysis

ECM-1: High-Performance HVAC System

Cadmus used the trend data for the installed equipment to verify the chilled water plant equipment demand and operating hours. Table 6 summarizes the average monthly outside air conditions, total chiller load, and equipment end-use demand from the trend data collection. We calculated the average chiller load using the individual chiller flow rates and supply and return water temperatures.

Table 6. Monthly Average Outside Air Conditions, Chiller Load, and Component Demand from Trend Data

Month and Year	Outside Air Wet Bulb Temp, °F	Average Total Chiller Load, tons	Average Total Chiller Demand, kW	Average Total CHWP Demand, kW*	Average Total CT Fan Demand, kW*	Average Total CWP Demand, kW*
7/2015	N/A	123.1	90.6	4.33	6.21	12.6
8/2015	N/A	144.3	88.9	4.23	5.32	12.2
9/2015	N/A	142.9	72.3	4.22	5.49	17.0
10/2015	N/A	83.4	46.5	4.27	5.31	30.5
11/2015	N/A	70.6	32.0	3.68	7.00	21.1
12/2015	N/A	75.4	39.0	3.71	7.15	23.3
1/2016	34.9	40.1	9.1	3.04	4.30	7.3
2/2016	40.0	54.1	16.6	3.37	5.25	14.5
3/2016	52.8	69.8	36.4	3.82	6.72	26.0
4/2016	55.2	76.3	43.5	3.75	7.02	21.5
5/2016	64.0	110.4	73.5	4.10	7.94	22.2
6/2016	72.0	138.6	101.3	4.43	8.94	14.5

* Chilled water pump (CHWP), cooling tower (CT) fan, and condenser water pump (CWP) output demand provided in trends (does not include VFD penalty).

Cadmus created an 8,760 hour model with TMY data for Charlotte, North Carolina. We plotted the trended installed case chiller load against outside air wet bulb temperature (see Figure 7), then used the linear trend fit from this plot to extrapolate the installed chiller load to the 8,760 hour model. The installed system uses a plate and frame heat exchanger as a water-side economizer to provide free-cooling when outside air conditions allow, so the total space load is greater than the installed case chiller load.

Since the load for a data center is fairly consistent throughout the year, we assumed that the minimum space cooling load is approximately 85% of the maximum load in the summer, or 125 tons. Using this assumption, the average annual cooling load is 127 tons, or 17% of the design load of 746 tons used in the application's eQuest model.

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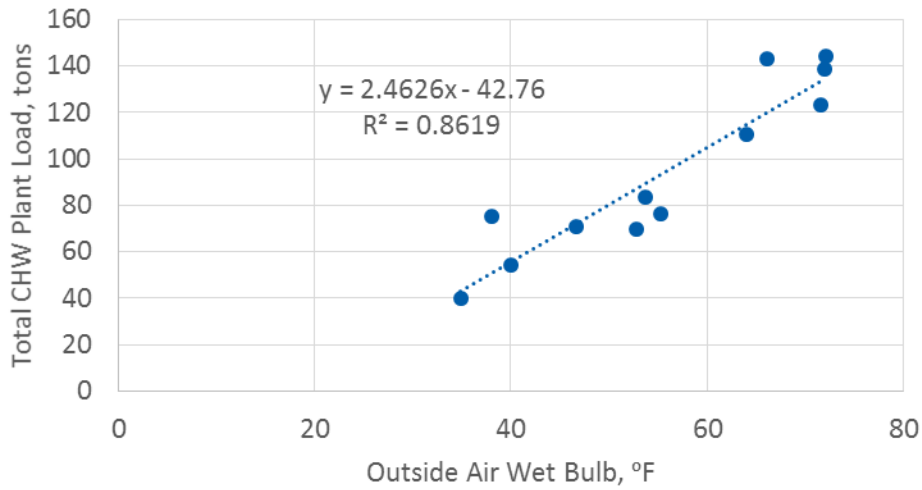
Figure 7. Trended Total Chiller Load vs. Outside Air Wet Bulb Temperature



We used the average monthly equipment trended demand from Table 6 (adding in the VFD penalty of 3% of the motor nameplate horsepower for the pumps and fans) in the installed system model. We estimated the air-side system demand for the computer room air handling unit (CRAH) fans using the following equations, with the assumed installed case air-side delta-T of 20°F and the calculated total cooling load:

Total Required Airflow, CFM = Total Cooling Load, Btu/hr / (1.08 * Delta-T, °F)

Total CRAH Fan BHP = Airflow, CFM * Total Pressure, inches WC / 6,356 * Fan Efficiency, %

Total CRAH Fan kW = CRAH Fan BHP * 0.746 kW / BHP / Motor Efficiency, %

Where:

Delta-T, °F	=	20.0°F
Total Pressure, inches water column (WC)	=	1.0 inches WC
Fan Efficiency, %	=	72%
Motor Efficiency, %	=	92%

The evaluated installed case annual energy use was 864,708 kWh. The coincident peak demand was 130.4 kW, and the average annual demand was 98.7 kW.

Cadmus based the baseline chiller performance curve on the same California Data Center Baseline document that was used in the original analysis. We then calculated the baseline chiller demand using the performance curve and the calculated total cooling load. The baseline chilled water pumps, cooling tower fans, and condenser water pumps are the same size as the installed case but are constant speed. Cadmus calculated the air-side system demand using the same methodology described in the installed case, but with an air-side system delta-T of 10°F as recommended in the California Data Center Baseline document. The evaluated baseline annual energy use was 1,378,940 kWh; coincident peak demand was 165.7 kW; and average annual demand was 157.4 kW.

Table 7 provides a breakdown of the evaluated baseline and installed annual energy use by equipment end use.

Table 7. Breakdown of Evaluated Baseline and Installed Equipment Annual Energy Use

Equipment End-User	Baseline Annual Energy Use, kWh	Installed Annual Energy Use, kWh
Chillers	718,305	476,121
Chilled Water Pumps	120,848	38,215
Condenser Water Pumps	143,110	172,832
Cooling Tower Fans	177,070	67,736
Airside System (CRAHs)	219,607	109,804
Total	**1,378,940**	**864,708**

Total evaluated energy savings based on the current load were 514,232 kWh (37% savings). The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 35.3 kW, and the average, or non-coincident, peak demand reduction was 58.7 kW. The greatest impact on the evaluated energy savings and demand reduction was that the evaluated average annual cooling load was only 17% of the system design load used in the original application's eQuest model. The site is still building out the data racks and has not come close to reaching capacity.

Figure 8 shows a comparison of the evaluated total system hourly demand of the baseline and installed HVAC systems.

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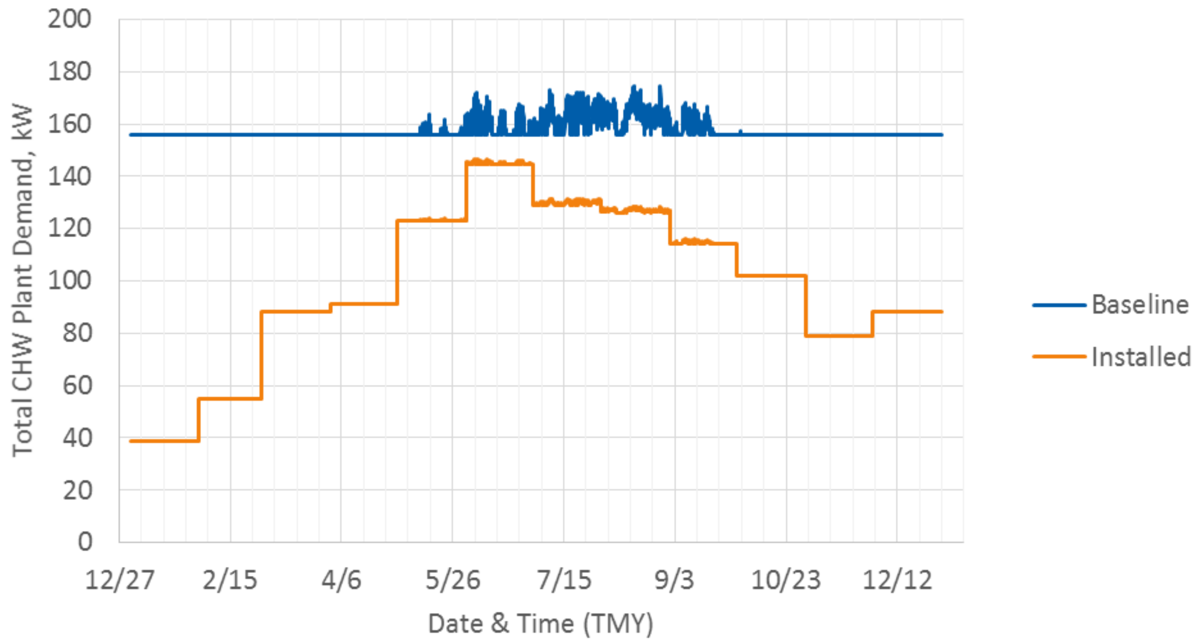
Figure 8. Comparison of Evaluated Total Baseline and Installed System Demand



Conclusion

While on the site, Cadmus found the equipment and controls installed as expected. Since the current load is only 17% of the design load and the site expects to increase the load over time, Cadmus calculated projected energy savings and demand reduction at an assumed load growth period of seven years. Seven years was used as a conservative estimate, since the facility manager estimated a five to seven year growth period.

Table 8 summarizes the projected and present value energy savings and demand reduction over the assumed seven-year load growth period. To calculate the projected savings and demand reduction, we assumed the load would increase linearly from 17% at Year 1 (current load) to 100% at Year 7 and that savings are directly related to load. We calculated the present value savings and demand reduction using an annual discount rate of 7.09% for North Carolina. This discount rate was provided to Cadmus by Duke Energy.

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Table 8. Projected and Present Value Energy Savings and Demand Reductions Over Assumed 7-Year Growth Period

Year	Assumed Average % Capacity	Annual Energy Savings, kWh		Peak Demand Reduction, kW		Average Demand Reduction, kW	
		Projected	Present Value	Projected	Present Value	Projected	Present Value
1	17.0%	514,232	514,232	35.31	35.31	58.71	58.71
2	30.9%	930,493	868,888	63.89	59.66	106.23	99.20
3	44.7%	1,346,753	1,174,330	92.46	80.63	153.76	134.07
4	58.5%	1,763,013	1,435,519	121.04	98.56	201.28	163.89
5	72.3%	2,179,273	1,656,975	149.62	113.76	248.80	189.17
6	86.2%	2,595,534	1,842,816	178.20	126.52	296.33	210.39
7	**100.0%**	**3,011,794**	**1,996,787**	**206.78**	**137.09**	**343.85**	**227.97**

* Evaluated energy savings and demand reductions based on data collected during M&V.

Based on these assumptions, the total projected energy savings at Year 7 were 1,996,787 kWh. The total summer coincident peak demand reduction at Year 7 (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 137.09 kW, and the average, or non-coincident, peak demand reduction was 227.97 kW.

The overall projected Year 7 energy savings realization rate was 69%, compared to the Duke Energy claimed savings. The summer peak demand realization rate was calculated as 59%. The average (or non-coincident) peak demand reduction realization rate was 90%.

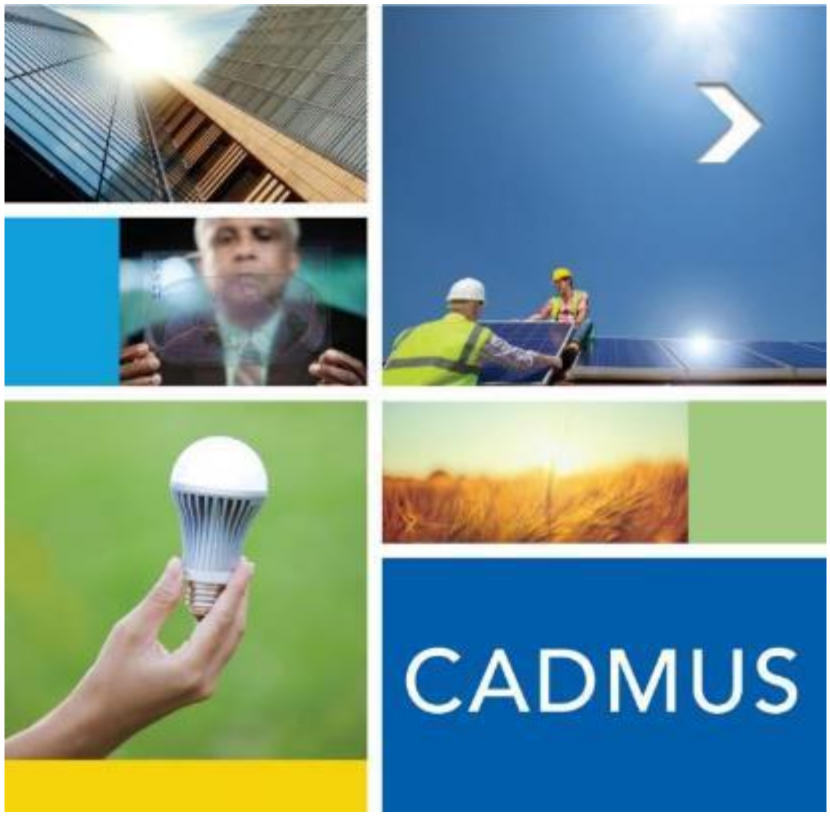
Table 9 provides a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 10 provides realization rates comparing the energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

Table 9. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

Applicant		Duke Energy Claimed			Evaluation		
Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
2,914,790	N/A	2,914,790	233.67	253.20	1,996,787	137.09	227.97

Table 10. Energy Savings and Demand Reduction Realization Rates

Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
69%	59%	90%



Application IDs 14-1706227 and 13-1547987 Compressed Air: M&V Report

August 5, 2016

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Cincinnati, OH 45201

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Introduction

This report addresses M&V activities for five energy conservation measures (ECMs), submitted in two [redacted], Smart $aver custom incentive program applications: 14-1706227 and 13-1547987. Descriptions follow of the measures included in each application (descriptions are based on the original project documentation).

14-1706227

Application CSN14-1706227 covers the three compressed air retrofit measures at the customer's location in [redeacted], NC. The [redacted] production facility has two separate compressed air networks: one to supply low-pressure compressed air requirements; and one to supply all other facility compressed air requirements. ECM-1 and ECM-2 apply to the low-pressure system and ECM-3 applies to the high-pressure system.

ECM-1—Low-Pressure Air Compressor Replacement

Pre-Retrofit: The pre-retrofit system consisted of seven 350-hp, Atlas Copco, load/unload, oil-flooded, rotary screw compressors, running the low-pressure system at 95 psi. The operation ran at a fairly consistent load 24 hours per day, seven days per week. One Sullair 300-hp VFD compressor on the low system operated as a trim machine. According to the technical assistance study, the pre-retrofit compressed air system operated at an average efficiency of 4.25 cfm/Bhp.

Installed: The installed case uses two FS Elliott P500-800, 800-hp, three-stage, water-cooled centrifugal compressors, rated for 4,485 cfm each at 95 psig compressed air. According to the technical assistance study, the installed system operates at an efficiency of 5.34 cfm/Bhp.

The existing Sullair VFD compressor continues to operate as a trim machine, and the seven existing Atlas Copco compressors have been kept as back-up compressors.

As the new compressors are water-cooled, an electric penalty exists for heat rejection. According to the original documentation, one new 20-hp pump was installed to operate with the existing process-load cooling tower to reject heat from the compressors.

ECM-2—Low-Pressure Air Dryer Replacement

Pre-Retrofit: Based on the technical assistance study, the nine pre-retrofit air dryers (with a combined rating of 100-hp) proved too small for the 300-hp air compressors. The dryers were manifolded together to allow enough flow to dry the air sufficiently. All dryers were required to operate, regardless of the number of compressors running.

Installed: The installed case uses two Zeks 4800NCFM, 4,800-acfm, refrigerated air dryers for the new compressors, with combined rating of 63-hp.

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ECM-3—High Pressure Dryer Replacement

Pre-Retrofit: The pre-retrofit system consisted of four, 250-hp, Atlas Copco, oil-flooded, rotary screw compressors, serving the high-pressure system at 188 psi. The operation served a fairly consistent load of ~1,000 cfm, 24 hours per day, seven days per week. One regenerative air dryer served the compressors.

The system, regulated from 188 psi in a 2½" pipe down to 125 psi in a 1½" pipe (prior to the dryer), fed a 370-cfm rated regenerative dryer. The pre-retrofit discharge pressure to the plant also was 105 psi, but this setting was found higher than necessary. The following issues arose with the pre-retrofit system:

1. The final discharge pressure to the plant should have been set at 95 psi, not 105 psi.
2. The 370 cfm dryer was not sized correctly to dry 1,000 cfm of compressed air.
3. The piping was too small to allow adequate flow.

Installed: By replacing the pre-retrofit dryer with a 1,000-cfm regenerative dryer and increasing the pipe size, pressure at the dryer inlet could be reduced from 125 psi to 95 psi. The flow would be reduced from 1,000 cfm to 760 cfm, according to the calculation below:

New Pressure (95 psi) / Existing Pressure (125 psi) * Existing Flow (1,000 cfm) = New Flow (760 cfm)

13-1547987

Application CSN13-1547987 involves two compressed retrofit measures at the customer's facility on [redacted] Street in [redacted].

ECM-1—New VFD Air Compressor

This measure involved the removal of three, existing, two-stage, Sullair, 300-hp air compressors and the installation of one, Sullair Tandem TS320-250LAC, 250-hp, VFD air compressor. Only one of the pre-retrofit compressors would operate during normal production periods; the second compressor would briefly turn on only for high demand periods.

This measure originally involved replacement of existing manual condensate drain valves with 10 zero-loss demand drains for condensate removal. As discussed below, this part of the measure was not installed, and updated energy savings calculations were submitted.

ECM-2—Compressed Air System Heat Recovery

This measure involved the installation of a heat recovery unit on the compressed air system, designed to reduce the need for electric resistance space heating during the winter months. The existing 440 kW electric resistance heating coils heated the entire [redacted] T2 building prior to the retrofit.

Goals and Objectives

Table 1 and Table 2 show the projected savings goals identified in the project applications.

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Table 1. 14-1706227 Project Goals

ECM	Application		Duke Energy			
	Annual kWh Savings	Average kW Reduction	Projected Annual Energy Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1 & 2	6,085,893	N/A	6,955,726	N/A	N/A	N/A
3	1,002,105	N/A	132,273	N/A	N/A	N/A
Total	**7,087,999**	**N/A**	**7,087,999**	**7,087,680**	**775.5**	**809.1**

* Source: DSMore input spreadsheet.

Table 2. 13-1547987 Project Goals

ECM	Applicant		Duke Energy			
	Annual kWh Savings	Average kW Reduction	Projected Annual Energy Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Savings
1	478,767	N/A	379,523	372,144	55.7	N/A
2	134,572	0	127,148	121,208	0.0	N/A
Total	**613,339**	**N/A**	**506,671**	**494,115**	**55.7**	**69.7**

* Source: DSMore input spreadsheet.

The M&V project sought to verify the actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization rates (kW and kWh)

Project Contacts

The Duke Energy contact listed in Table 3 granted approval to plan and to schedule the site visit for this M&V effort.

Table 3. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Frankie Diersing	office: 513-287-4096 Frankie.diersing@duke-energy.com
Cadmus	Christie Amero	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

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Site Locations

The locations where the measures were installed are shown in Table 4.

Table 4. Project Locations

Address	ECM
redacted	1, 2, & 3 (CSN14-1706227)
redacted	1 & 2 (CSN13-1547987)

M&V Option

To assess these projects, Cadmus utilized IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. The site contact confirmed that trend data were available and the metering could be performed while de-energized. Christie Amero and Tom Davis of Cadmus performed the site visit on January 6, 2016.

Field Notes

Upon arriving on site, Cadmus first met to discuss the metering plan with the facility management team for both buildings. At both sites, the compressed air discharge pressure has remained constant since before project implementation. Depending on the season, production has increased slightly, and minor changes have occurred in the production schedule. Site and measure-specific notes follow.

14-1706227

The [redacted] facility operates 24 hours per day, seven day per week, year-round. During the inspection, the facility operated in its busy season.

ECM-1 & 2—Low-Pressure Air Compressor and Dryer Replacements

Rather than installing 800-hp air compressors as expected, the site installed two 900-hp air compressors. This selection change was due to a last-minute decision based on production forecasting. According to the equipment vendor, the installed units are considered to be the same model that was submitted in the application (P500-800) even though they were installed with 900 hp motors.

The site also replaced the 480 V feed for the 900-hp compressors with a 4,160 V feed. As Cadmus cannot meter above 480 V, we revised the plan to collect power demand and pressure trend data for the two 900-hp compressors.

The pre-retrofit Atlas Copco compressors remained on-site, but they were off and only used as back-ups. The existing Atlas Copco, 300-hp, VFD compressor also was off during the site visit and is rarely used, according to the site contact.

As expected, the site installed two Zeks air dryers for the low-pressure system.

A change also occurred to the cooling tower pumps: rather than two 20-hp pumps, the site installed two 40-hp cooling tower pumps. The pumps operate lead/lag. The cooling tower served by the pumps has two fans, both with VFDs. One fan ran at 15 Hz during the inspection.

ECM-3—High-Pressure Dryer Replacement

Cadmus verified the 1,000 CFM air dryer had been installed, but could not meter it as it is served by a 120 V feed. The operating current during the inspection was only 4 amps; it was determined that manufacturer's data would serve to identify its energy use. During the walkthrough the pressure was 103 psi.

Cadmus did not meter the four existing Atlas Copco air compressors.

13-1547987

The [redacted] facility typically operates 24 hours per day, Monday through Friday, but the schedule varies slightly, based on demand.

ECM-1—New VFD Air Compressor

Cadmus verified the installation of the new 250-hp, VFD air compressor.

The zero-loss condensate drains expected from the project documentation were not installed. The site contact stated that they did not plan to install the drains and did not receive an incentive for that portion of the project.

ECM-2—Compressed Air System Heat Recovery

Cadmus verified the installation of the compressed air heat recovery duct. The heated air is ducted directly from the 250-hp air compressor into a mixing room, where outside air is drawn in for humidification. The mixed air is then fed through electric duct heaters into the warehouse space.

Field Data

Cadmus collected the following: equipment nameplate data, power metered data, and photographs for each application.

14-1706227

Table 5 summarizes equipment nameplate data collected at the [redacted] location. Photographs of equipment and nameplates follow.

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Table 5. 14-1706227 Equipment Nameplate Data

Equipment ID	Make	Model Number	Serial Number	Size/Rating
900-hp Comp-1 (LP)	FS Elliot	P500-800	N/A	900 hp
900-hp Comp-2 (LP)	FS Elliot	P500-800	N/A	900 hp
300-hp VFD Comp (LP)	Atlas Copco	GA 315 VSD	APF.143057	300 hp
Dryer-1 (LP)	Zeks	4800NCFMA40NV	554076-1	4,800
Dryer-2 (LP)	Zeks	4800NCFMA40NV	554076-2	4,800
1000 CFM Dryer (HP)	Zeks	1000ZPA1HE000	554060	1,000 CFM
CT Pump-1 (LP)	Armstrong	6x6xB.5 4300TC	762750	40 hp
CT Pump-2 (LP)	Armstrong	6x6xB.5 4300TC	762751	40 hp

Figure 1 shows a screenshot of the EMS for the low-pressure compressed air system. Figure 2 shows installed air dryers for the low-pressure system. Figure 3 shows the dryer nameplates.

Figure 1. Screenshot of EMS for Low-Pressure System

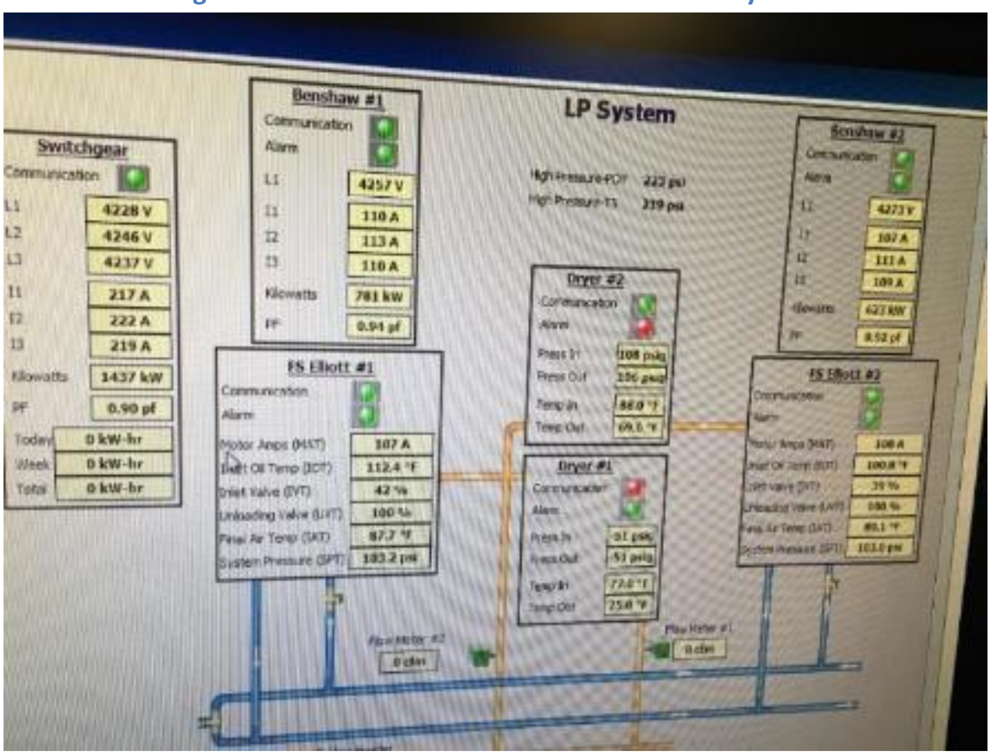

Figure 2. Installed 4,800 CFM Air Dryers for Low-Pressure System

Figure 3. Installed 4,800 CFM Air Nameplates

Figure 4 shows the nameplate for the existing 300-hp, VFD air compressor. Figure 5 shows the two cooling tower pumps for the water-cooled air compressors. Figure 6 shows a nameplate for one pump.

Figure 4. Existing 300-hp VFD Air Compressor

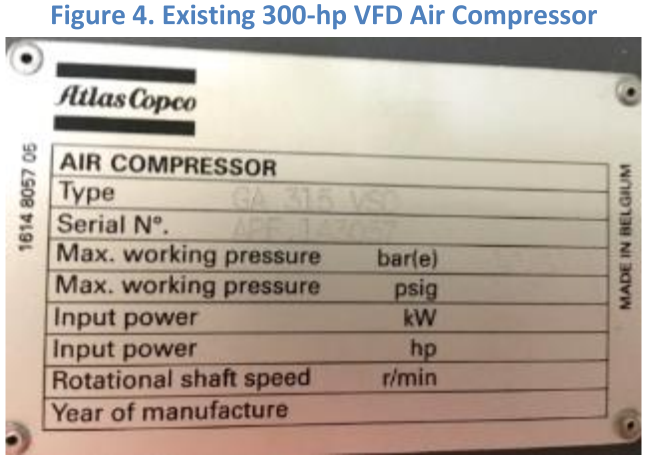

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Figure 5. 40-hp Cooling Tower Pumps for Water-Cooled Air Compressors

Figure 6. 40-hp Cooling Tower Pump Nameplate

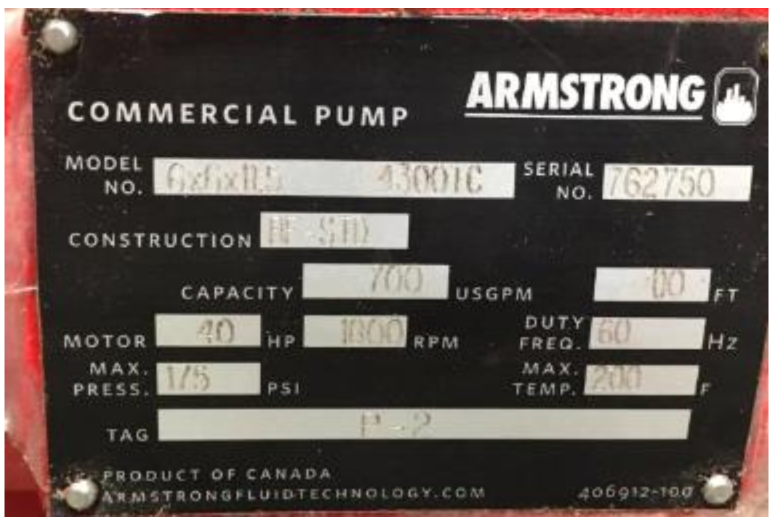

Figure 7 shows the nameplate for the installed 1,000 cfm air dryer for the high-pressure compressed air system.

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Figure 7. Installed 1,000 CFM Air Dryer for High-Pressure System

As the installed 900-hp air compressors are served by ~4,200 V, Cadmus collected compressor demand and pressure trend data from the site for a two-week period. Figure 8 shows the combined power demand for the two 900-hp air compressors from the trend data. Average operating demand was 1,299.8 kW. Figure 9 shows the trended system discharge pressure. The average pressure during the trend period was 104.2 psi.

Figure 8. Trended Demand Data for Installed 900-hp Air Compressors

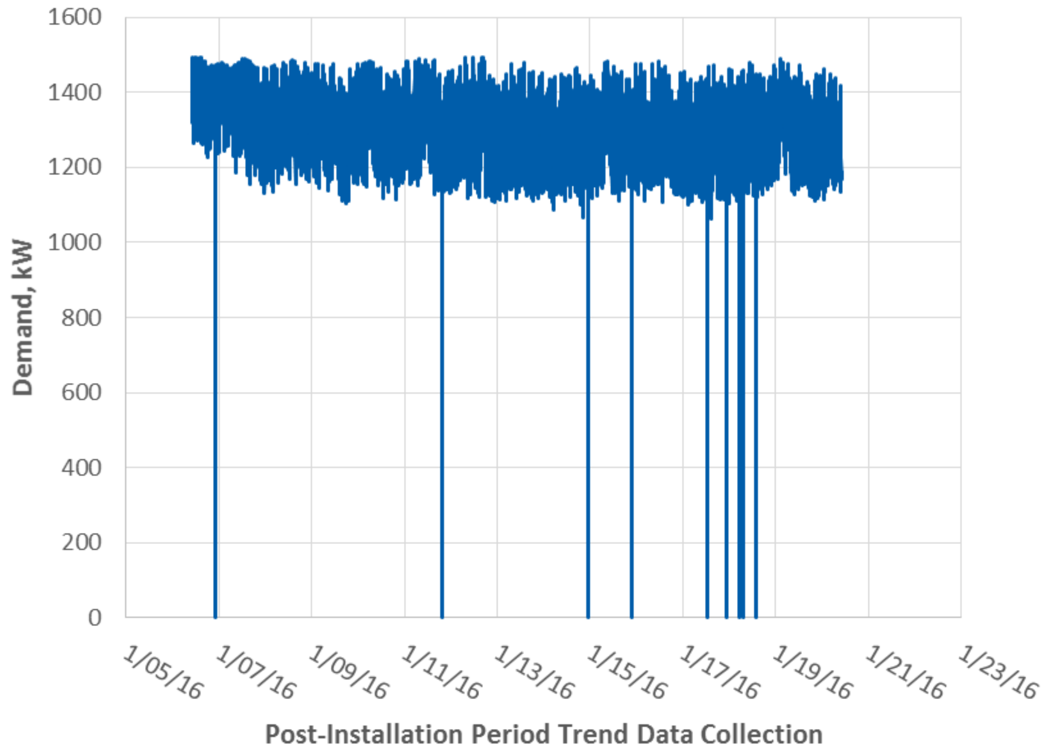
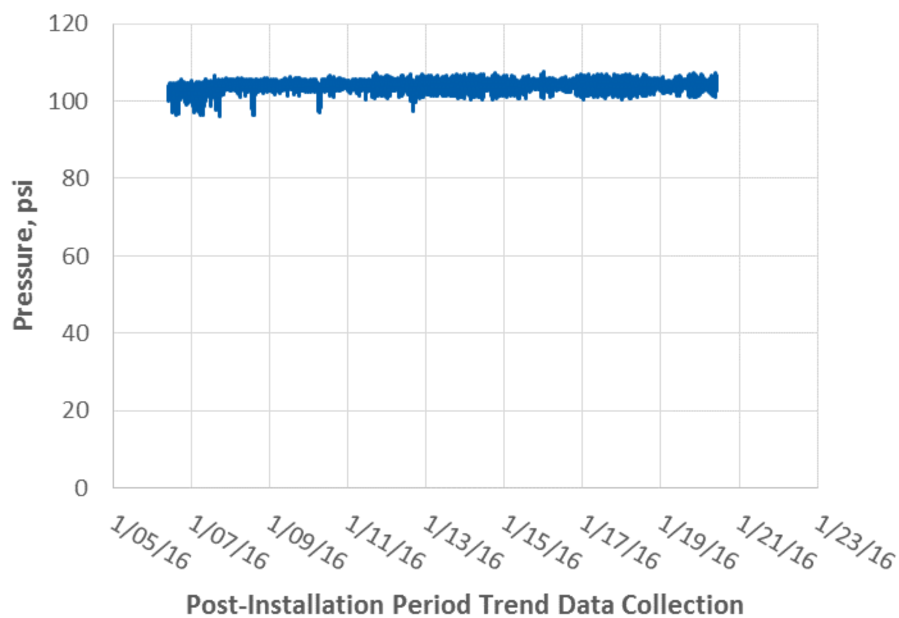


Figure 9. Trended System Discharge Pressure for Low-Pressure System



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Cadmus installed three-phase power meters on the remaining 300-hp, VFD air compressor, two air dryers, and cooling tower pumps for the low-pressure system. Data were collected for two weeks at one-minute intervals. Table 6 summarizes the installed metering equipment.

Table 6. 14-1706227 Summary of Installed Metering Equipment

Equipment ID	RX3000	WattNode 3D-480	Current Transducers (Qty/Size)
VFD Air Comp	1	1	3 / 1200 A
Dryer-1 (LP)	1	1	3 / 100 A
Dryer-2 (LP)		1	3 / 100 A
CT Pump-1	1	1	3 / 100 A
CT Pump-2		1	3 / 100 A
Total	**3**	**5**	**15**

As expected, the 300-hp VFD air compressor never ran during the metering period. Figure 10 shows metered demand data for the two, 4,800 cfm air dryers for the low-pressure system. Figure 11 shows metered demand for the two cooling pumps. Only one pump ran during the metering period.

Figure 10. Metered Demand Data for Low-Pressure Air Dryers

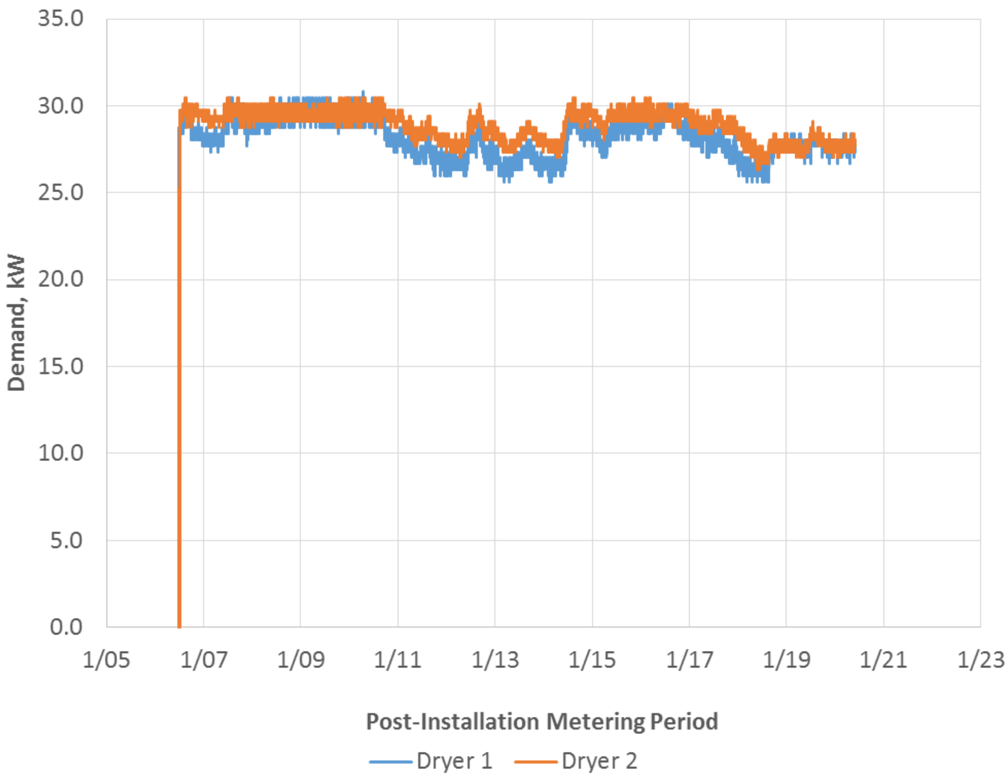
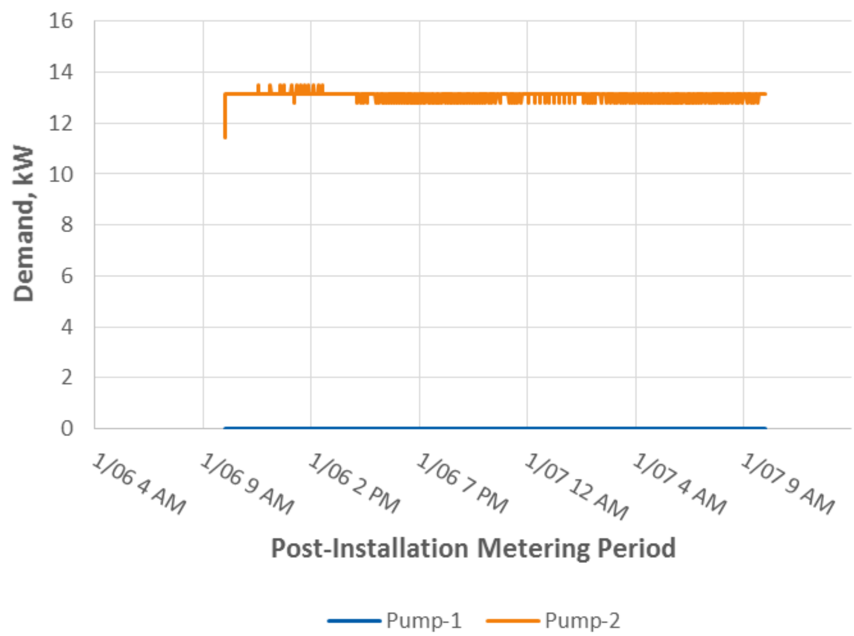


Figure 11. Metered Demand Data for Cooling Tower Pumps



13-1547987

Table 7 summarizes equipment nameplate data collected at the [redacted] location.

Table 7. 13-1547987 Equipment Nameplate Data

Equipment ID	Make	Model Number	Serial Number	hp
VFD Comp	Sullair	V320TS 250AC	201312200008	250
Heat Recovery	N/A	N/A	N/A	N/A

Figure 12 shows the nameplate for the installed 250-hp, VFD air compressor. Figure 13 shows the control screens for the air compressor. During the inspection, the compressor's discharge air pressure was 99 psi and the percent capacity was 62%.

Figure 12. 250-hp VFD Air Compressor Nameplate

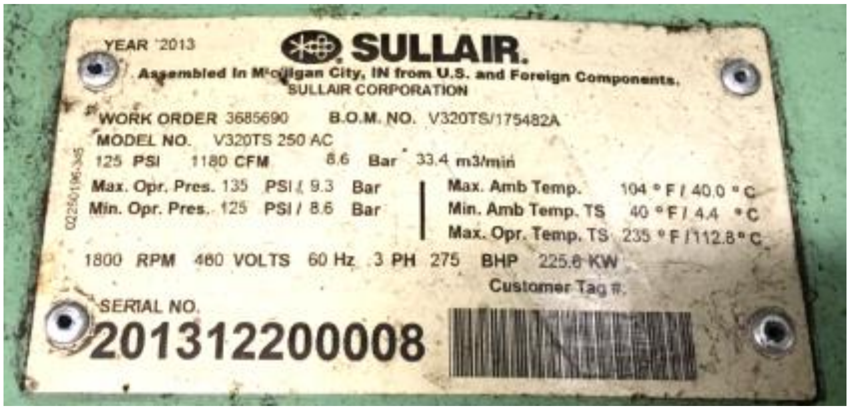


Figure 13. 250-hp VFD Air Compressor Control Screens

Figure 14 shows the compressed air heat recovery system. The image on the right shows the duct removing heat from the compressor; the image on the left shows the mixing room where the heated air is dumped (duct on top) and mixed air is fed into the warehouse through electric duct heaters (bottom).

Figure 14. Compressed Air Heat Recovery System

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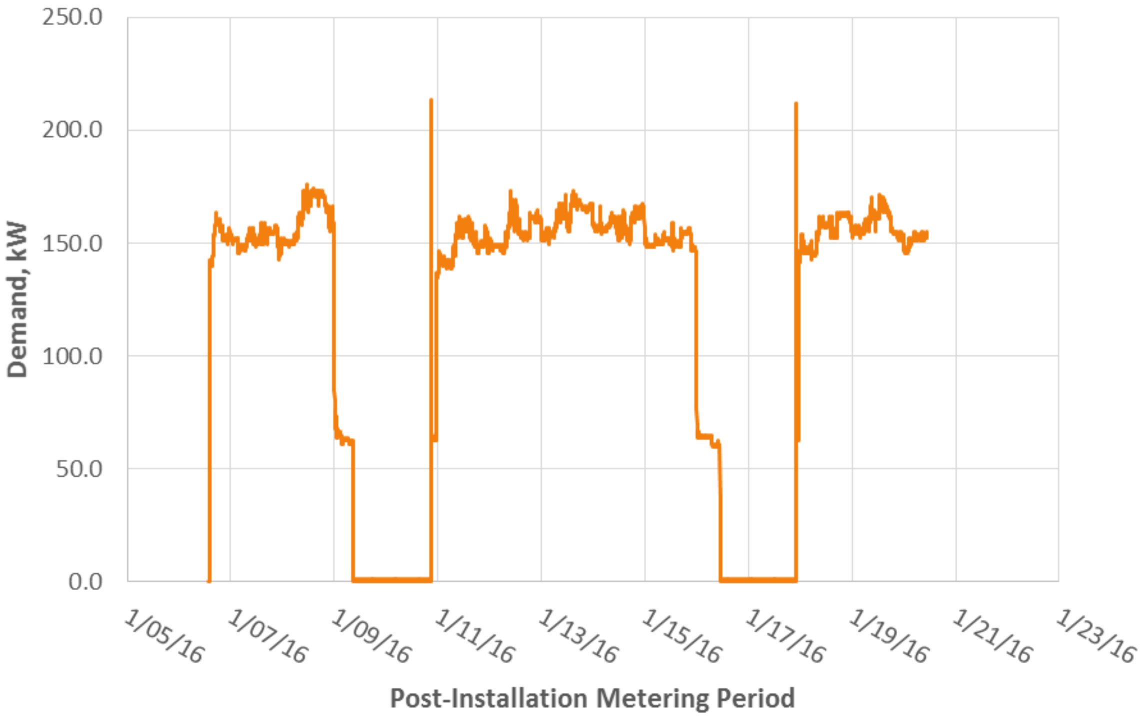
Cadmus installed two three-phase power meters on the 250-hp, VFD air compressor. One power meter was set up with 100 A CTs and one was set up with 400 A CT to capture compressor demand at high and low VFD speeds. Data were collected for two weeks at one-minute intervals. Table 8 summarizes the installed metering equipment, and Figure 15 shows the meter installation. Figure 16 summarizes the metered demand data for the 250-hp air compressor.

Table 8. 13-1547987 Summary of Installed Metering Equipment

Equipment ID	RX3000	WattNode 3D-480	Current Transducers (Qty/Size)
VFD Air Comp	1	1	3 / 400 A
		1	3 / 100 A
Total	**1**	**2**	**6**

Figure 15. 250-hp VFD Air Compressor Meter Equipment Setup

Figure 16. Metered Demand Data for 250-hp VFD Air Compressor



Cadmus used a hand-held anemometer and an IR temperature gun to spot-measure the airflow and to log the temperature of the heated air at various areas of the heat recovery duct. Table 9 provides the temperature readings for the heat recovery duct and the mixing room. Table 10 shows the airflow measurements.

Table 9. Heat Recovery Duct Temperature Spot Measurements

#	Duct Temperature, °F	Mixing Room Temperature, °F
1	86.1	65.0
2	89.2	60.2
3	93.4	67.8
4	92.3	66.8
5	94.6	65.2
6	95.9	62.0
7	97.2	-
Average	**92.7**	**64.5**

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Table 10. Heat Recovery Duct Airflow Spot Measurements

#	Airflow, SCFM
1	750
2	605
3	659
4	801
5	731
6	725
7	671
8	843
9	825
10	700
11	538
12	559
Average	**700.6**

Data Accuracy

Table 11. Metering Equipment Accuracy

Measurement	Sensor	Accuracy	Notes
Demand, kW	WattNode Power Meter	±1%	
Current, amps	Magnelab CT	±1%	Recorded load must be < 130% and > 10% of CT rating.

Data Analysis

14-1706227

ECM-1 – Low-Pressure Air Compressor Replacements

Cadmus used the trend data and vendor's performance curves for the installed compressors to verify the installed case equipment demand and operating hours. The two 900-hp air compressors ran constantly during the trend data collection period at an average demand of 1,299.8 kW.

Since the site does not have airflow meters on the installed air compressors, and did not have flow meters on the pre-retrofit air compressors, Cadmus used performance data for the installed air compressors to estimate the compressed air load at the site. The vendor's performance curve (see Figure 17) shows a compressor performance of 5.84 cfm/kW at a design load of 3,833 cfm, assuming a motor efficiency of 96.2%. Cadmus then estimated that the site's total airflow load during the trend data collection was approximately 7,590 cfm based on the equation below.

Airflow, cfm = Trended Demand, kW * Performance, cfm/kW

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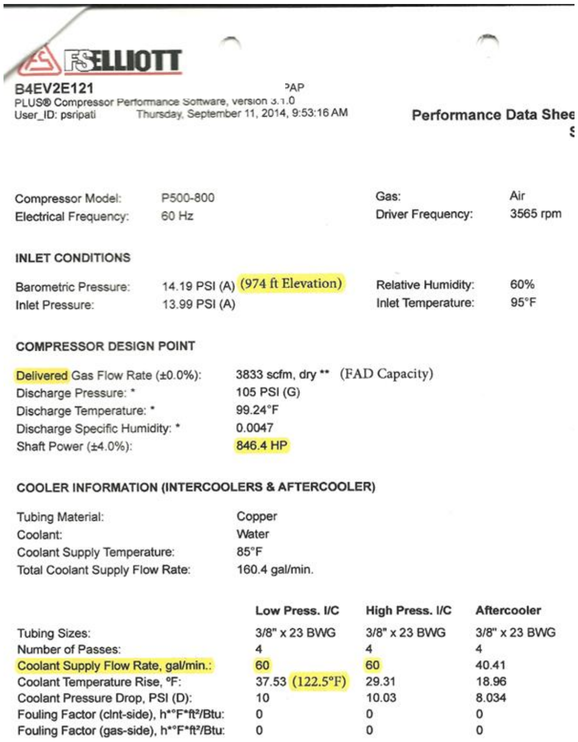
Figure 17. Design Conditions and Performance Curve for Installed Air Compressors



FS ELLIOTT
B4EV2E121 PAP PLUS® Compressor Performance Software, version 3.1.0
User_ID: psripati Thursday, September 11, 2014, 9:53:16 AM

Performance Data Shee

Compressor Model:	P500-800	Gas:	Air
Electrical Frequency:	60 Hz	Driver Frequency:	3565 rpm

INLET CONDITIONS

Barometric Pressure:	14.19 PSI (A) (974 ft Elevation)	Relative Humidity:	60%
Inlet Pressure:	13.99 PSI (A)	Inlet Temperature:	95°F

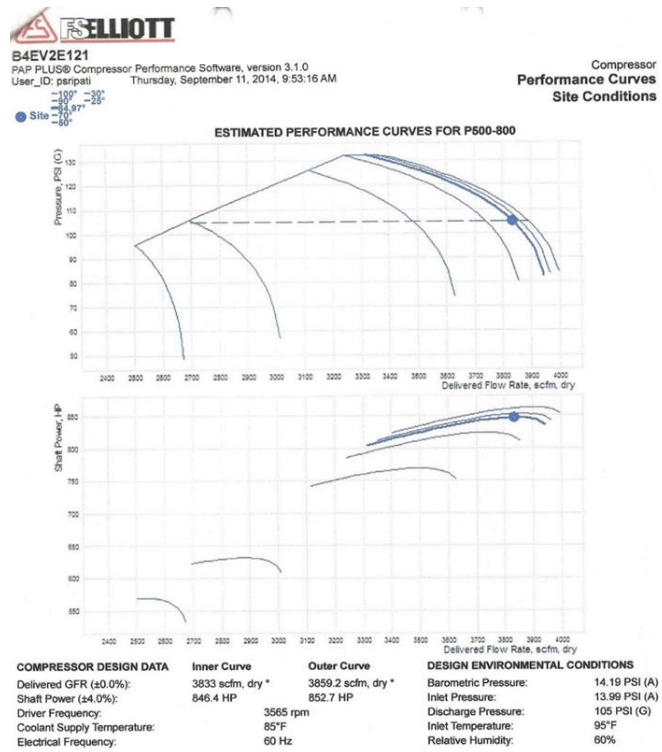
COMPRESSOR DESIGN POINT

Delivered Gas Flow Rate (±0.0%):	3833 scfm, dry ** (FAD Capacity)
Discharge Pressure: *	105 PSI (G)
Discharge Temperature: *	99.24°F
Discharge Specific Humidity: *	0.0047
Shaft Power (±4.0%):	846.4 HP

COOLER INFORMATION (INTERCOOLERS & AFTERCOOLER)

Tubing Material:	Copper
Coolant:	Water
Coolant Supply Temperature:	85°F
Total Coolant Supply Flow Rate:	160.4 gal/min.

	Low Press. I/C	High Press. I/C	Aftercooler
Tubing Sizes:	3/8" x 23 BWG	3/8" x 23 BWG	3/8" x 23 BWG
Number of Passes:	4	4	4
Coolant Supply Flow Rate, gal/min.:	60	60	40.41
Coolant Temperature Rise, °F:	37.53 (122.5°F)	29.31	18.96
Coolant Pressure Drop, PSI (D):	10	10.03	8.034
Fouling Factor (clnt-side), h*°F*ft²/Btu:	0	0	0
Fouling Factor (gas-side), h*°F*ft²/Btu:	0	0	0



Based on the performance curve above, the maximum airflow for the installed air compressors is 3,940 cfm each, or 7,880 cfm total. Cadmus then estimated the plant's compressed air load during the trend period at 96% (7,590 cfm/7,880 cfm). We then used the performance curves for the installed and pre-retrofit air compressors to calculate the energy required to meet the required load.

Table 12 compares the evaluated installed case overall system performance at various loads. Based on the trended demand data and screenshots of the EMS, which showed both three-stage air compressors operating at comparable power demand, we assumed the installed compressors would share the load equally down to approximately 70% load. Below 70% load, one three-stage air compressor would be able to meet the load. At very low loads, only the existing VFD air compressor would operate.

Table 12. Evaluated Installed Compressed Air System Performance at Various Loads

Percent Load	Compressed Airflow, cfm	Control Description	FS Elliot 3-Stage (2)		VFD (1)		Overall cfm/kW
			Total cfm	cfm/kW	Total cfm	cfm/kW	
100%	7,880	2 3-stage	7,880	6.12	0	0.00	6.12
96%	7,590	2 3-stage	7,590	5.79	0	0.00	5.79
80%	6,304	2 3-stage	6,304	5.00	0	0.00	5.00
60%	4,728	1 3-stage, 1 VFD	3,500	5.35	1,228	5.34	5.35
40%	3,152	1 3-stage	3,152	5.00	0	0.00	5.00
20%	1,576	1 VFD	0	0.00	1,576	5.37	5.37

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As shown in Table 12, Cadmus estimated the overall installed case system performance at 96% load to be 5.79 cfm/kW. We assumed the annual operating hours are 8,760 hours based on the trend data and discussions with the facility manager. The evaluated installed case energy use is 11,484,545 kWh and the average and peak demand is 1,311.0 kW.

Cadmus collected performance curves for the pre-retrofit air compressors. Table 13 compares the evaluated pre-retrofit overall system performance at various loads. We assumed the load/unload air compressors would be operated up to approximately 80% load before the next load/unload compressor would be turned on and the VFD air compressor would be used for trim. As shown in Table 13, Cadmus estimated the overall pre-retrofit system performance at 96% load to be 4.85 cfm/kW. Pre-retrofit annual operating hours were assumed equal to the installed case. The evaluated pre-retrofit energy use is 13,705,820 kWh and the average and peak demand is 1,564.6 kW.

Table 13. Evaluated Pre-Retrofit Compressed Air System Performance at Various Loads

Percent Load	Compressed Airflow, cfm	Control Description	Load/Unload (8)		VFD (1)		Overall
			Total cfm	cfm/kW	Total cfm	cfm/kW	cfm/kW
100%	7,880	6 load/unload, 1 VFD	7,051	4.71	829	4.93	4.73
96%	7,590	5 load/unload, 1 VFD	5,876	4.71	1,714	5.33	4.85
80%	6,304	4 load/unload, 1 VFD	4,701	4.71	1,603	5.37	4.88
60%	4,728	3 load/unload, 1 VFD	3,526	4.71	1,202	5.34	4.87
40%	3,152	2 load/unload, 1 VFD	2,350	4.71	802	4.90	4.76
20%	1,576	1 VFD	0	0.00	1,576	5.37	5.37

Figure 18 compares the evaluated pre-retrofit and installed case energy use at various compressed air loads. The potential energy savings are highest at high compressed air loads. At very low loads there are no potential savings as only the existing VFD air compressor would operate in both the pre-retrofit and installed cases.

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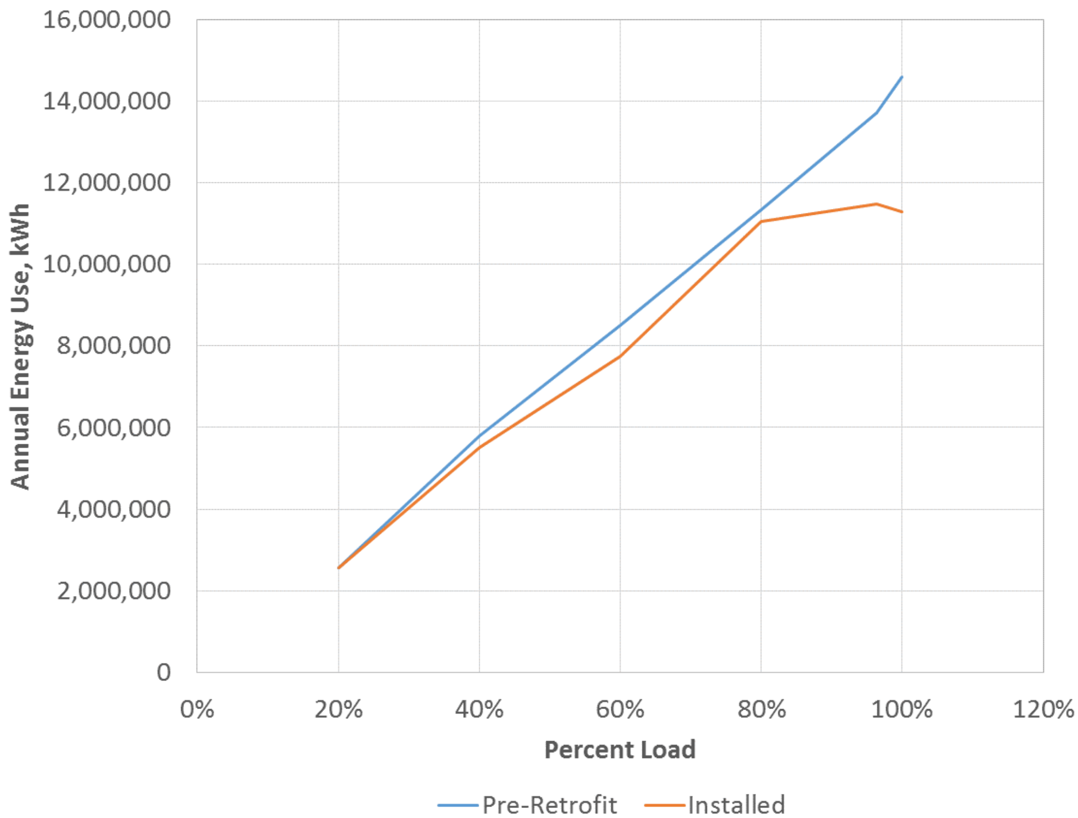
Figure 18. Energy Use Comparison at Various Loads



The evaluated energy savings from this measure are 2,221,275 kWh (16% savings). The annual average (or non-coincident) peak demand reduction is 253.57 kW, and the summer peak coincident demand reduction (July, Monday–Friday, 4:00 pm–5:00 pm) is 253.57 kW.

ECM-2 – Low-Pressure Dryer Replacement

Cadmus used the power metered data and trend data for the installed pumps and dryers to verify the installed case equipment demand and operating hours.

The two 1,000-cfm air dryers and one 40-hp cooling tower pump ran constantly during the metering period. Average energy use was calculated by multiplying the average metered demand by total annual operating hours (8,760 hours). The evaluated installed case energy use is 613,648 kWh, with average and peak demands of 70.1 kW.

Pre-retrofit demand for the nine air dryers was based on the original study. The study collected input demand for each dryer. Pre-retrofit annual operating hours were assumed equal to the installed case. The evaluated pre-retrofit energy use is 766,610 kWh. Average and peak demand is 87.5 kW.

The evaluated energy savings from this measure are 152,963 kWh. The annual average peak demand reduction is 17.46 kW, and the summer peak coincident demand reduction is 17.46 kW.

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ECM-3—Compressed Air System Heat Recovery

Cadmus did not meter the four existing 250-hp Atlas Copco air compressors for the high-pressure system but performed a desk review of the calculations submitted in the original application. Since it was unclear how the original study calculated compressor demand in the pre- and post-retrofit cases, Cadmus used manufacturer's data and compressor performance curves to verify the demand.

The evaluated installed case energy use for the high-pressure system is 5,324,692 kWh. The average and peak demands are 607.8 kW.

The evaluated pre-retrofit energy use for the high-pressure system is 6,721,027 kWh. The annual average and peak coincident demands are 767.2 kW.

Evaluated annual energy savings for this measure are 1,396,335 kWh. The average demand reduction and peak coincident demand reduction is 159.4 kW.

The installed air dryer was operating at 4 amps during the site inspection and uses minimal electric energy (~3,400 kWh/year). Since Cadmus did not have access to the pre-retrofit dryer model number, the energy use for the pre- and post-retrofit air dryers was not included in the energy savings calculation.

The evaluated total annual energy savings for this application are 3,770,573 kWh. The average demand reduction is 430.4 kW. The summer peak coincident demand reduction is 430.4 kW.

13-1547987

ECM-1—New VFD Air Compressor

Cadmus used the power metered data to verify installed compressor demand and operating hours. Average weekly operating demand is 125.4 kW, and average percent operating is 82%. Evaluated installed case energy use is 896,280 kWh. Annual average demand is 102.3 kW, and summer peak coincident demand is 155.7 kW.

As Cadmus did not have access to trend data for the [redacted] location, the pre-retrofit compressor average demand of 208.8 kW was based on the original study. Operating hours were assumed equal to the installed case. Evaluated pre-retrofit energy use is 1,492,367 kWh. The average demand is 170.4 kW, and the summer peak coincident demand is 208.8 kW.

Evaluated energy savings for this measure are 596,087 kWh. The annual average demand reduction is 68.0 kW, and the summer peak coincident demand reduction is 53.0 kW.

ECM-2—Compressed Air System Heat Recovery

Cadmus used the spot measurements shown in Table 9 and Table 10 to verify energy savings from the heat recovery duct. The average duct output temperature is 92.7°F, and the average mixing room temperature is 64.5°F. The average airflow provided by the duct is 700.6 cfm.

Assuming the average outside air temperature during the heating months is 30°F, the ratios of the heated air from the compressor and outside air are 55% and 45%, respectively. Total airflow provided to the warehouse was estimated to be the duct airflow divided by 55%, or 1,274 cfm.

According to the site contact, the warehouse is maintained at ~65°F. In the pre-retrofit case, 100% of the air supplied to the space would have been unheated outside air. The average heating demand in the pre-retrofit case was calculated as 48,149 Btu/hr using the following equation:

Pre-Retrofit Heating Demand, Btu/hr =
1.08 * (Space Temp, 65°F – OAT, 30°F) * Total Airflow, 1,274 cfm

The installed case heating demand was calculated at 730 Btu/hr, as follows:

Post-Retrofit Heating Demand, Btu/hr =
1.08 * [Space Temp, 65°F – (Duct Temp, 92.7°F * 55% + OAT, 30°F * 45%)] *
Total Airflow, 1,274 cfm

Heating demand savings are 47,419 Btu/hr. As the efficiency of the electric heaters is 100%, electric demand reduction is 13.9 kW. The original study stated that heating was in use for three months of the year, or 2,190 hours. Heating energy savings are 30,436 kWh.

A slight demand penalty arises from the 5-hp heat recovery supply fan. The fan motor efficiency is 87.5%, based on the nameplate, and the load factor is assumed to be 85%; therefore, fan demand is 3.6 kW, and the energy use during the heating months is 7,935 kWh.

Evaluated net energy savings for this measure are 22,501 kWh. Average demand reduction is 10.3 kW. The summer peak coincident demand reduction is 0.0 kW as the heaters would not operate during the summer months.

Evaluated total annual energy savings for this application are 618,587 kWh. Annual average demand reduction is 78.3 kW, and summer peak coincident demand reduction is 53.0 kW.

Conclusion

A summary of the findings and realization rates follow for each application.

14-1706227

Cadmus found most of the equipment installed as expected. The installed cooling tower pumps were 40-hp, compared to the 20-hp expected. The overall annual energy savings realization rate was 53%. The summer coincident peak demand reduction realization rate was 56%. The annual average demand reduction realization rate was 53%. The decrease in energy savings is attributed to the following:

- The installed three-stage air compressors for the low pressure system have a lower performance than expected in the original analysis.

- The original analysis contained minor errors that had a high impact on overall energy savings and demand reduction.

The results of this project emphasize the importance of airflow meters in developing accurate load profiles. Without airflow data, it is difficult to determine whether the compressors are blowing off and what the actual load in the plant is. Cadmus determined the ECM-1 measure savings based on a thorough review of the current compressed air demand and pre-retrofit and installed equipment performance data.

Table 14 provides a comparison of the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction. Table 15 provides the realization rates, compared to energy savings and demand reductions claimed by Duke Energy.

Table 14. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

ECM	Applicant	Duke Energy Claimed			Evaluation		
	Annual kWh Savings	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	CP kW Reduction	Non-CP kW Reduction
1 & 2	6,085,893	N/A	N/A	N/A	2,374,238	271.0	271.0
3	1,002,105	N/A	N/A	N/A	1,396,335	159.4	159.4
Total	**7,087,999**	**7,087,680**	**775.0**	**809.0**	**3,770,573**	**430.4**	**430.4**

Table 15. Energy Savings and Demand Reduction Realization Rates

ECM	Annual kWh Savings	Coincident Peak kW	Non-Coincident Peak kW
1 & 2	N/A	N/A	N/A
3	N/A	N/A	N/A
Total	**53%**	**56%**	**53%**

13-1547987

Cadmus found the equipment installed as expected. Duke Energy already knew the zero-loss condensate drains had not been installed. Energy savings for the new VFD compressor were higher than expected as average metered demand was ~18% less than expected and operating hours were ~4% higher than expected. Energy savings for the heat recovery system were lower than expected. The original study assumed that, in the pre-retrofit case, the electric heaters would have operated at 100% load during the three-month heating season, which overstated the energy use.

The overall energy savings realization rate was 125%. The summer coincident peak demand reduction realization rate was 95%. The average demand reduction realization rate was 112%.

CADMUS

Table 16 provides a comparison of the applicant, Duke Energy claimed, and evaluation energy savings and demand reduction. Table 17 provides the realization rates, compared to energy savings and demand reductions claimed by Duke Energy.

Table 16. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

ECM	Applicant	Duke Energy Claimed			Evaluation		
	Annual kWh Savings	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	CP kW Reduction	Non-CP kW Reduction
1	478,767	372,144	55.7	N/A	596,087	53.0	68.0
2	134,572	121,208	0.0	N/A	22,501	0.0	10.3
Total	**613,339**	**494,115**	**55.7**	**69.7**	**618,587**	**53.0**	**78.3**

Table 17. Energy Savings and Demand Reduction Realization Rates

ECM	Annual kWh Savings	Coincident Peak kW	Non-Coincident Peak kW
1	160%	95%	N/A
2	19%	100%	N/A
Total	**125%**	**95%**	**112%**

Application ID 13-1593207
Lighting Retrofit
M&V Report

Prepared for
Duke Energy Carolinas

January 2015, Version 1.0
(Revised August 22, 2016)

Note: This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and [redacted].

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On August 22, 2016 the Duke Energy projected savings in this report were corrected by Cadmus to correspond to Duke Energy expected savings as found in the Duke Energy program tracking database.

Introduction

This document addresses the M&V activities for the lighting retrofit at [redacted] in [redacted], North Carolina. This lighting retrofit was rebated through Duke Energy's Smart $aver Custom Lighting Incentive program. The following ECMs were implemented as part of this application.

- **ECM-1 –** Retrofitted (1) 85W 4' 1L T12 fixture with 2L 4' F28T8 fixture.
- **ECM-2 –** Retrofitted (30) 125W 8' 1L T12 fixtures with 4' 2L F28T8 fixtures.
- **ECM-3 –** Retrofitted (1) 145W 4' 2L T12 fixture with 4' 2L F28T8 fixture.
- **ECM-4 –** Retrofitted (69) 80W 4' 2LT12 fixtures with 4' 2L F28T8 fixtures.
- **ECM-5 –** Retrofitted (112) 80W 4' 2L T12 fixtures with 4' 2L F17T8 fixtures.
- **ECM-6 –** Retrofitted (3236) 227W 8' 2L T12 fixtures with 4' 2L F28T8 fixtures.
- **ECM-7 –** Retrofitted (144) 160 W 4' 4L T12 fixtures with 4' 2L F28T8 fixtures.
- **ECM-8 –** Retrofitted (2429) 227W 8' 2L T12 fixtures with 4' 4L F28T8 fixtures.
- **ECM-9 –** Removed (266) 455 W Metal Halide fixtures.

Goals and Objectives

A post-retrofit survey of the lighting usage was conducted to determine the power reduction from the lighting upgrade.

The projected savings goals are:

Facility	Application Annual kWh savings	Application kW Savings	Duke Projected Annual kWh savings	Duke Projected kW savings
redacted	6,802,289	793	7,928,096	902
Total	**6,802,289**	**793**	**7,901,837**	**902**

The objective of this M&V project will be to verify the actual:

- Annual gross kWh savings
- Summer peak kW savings
- Coincidence Peak kW savings
- kWh & kW Realization Rates

Project Contacts

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Customer Contact	redacted	

Site Locations/ECM's

Address	ECMs Implemented
redacted	1-9

Data Products and Project Output

- Post retrofit survey of lighting fixtures.
- Average post-retrofit lighting fixture load shapes.
- Equivalent Full Load Hours (HOURS) by day type (weekday/weekend).
- Summer peak demand savings.
- Summer utility coincident peak demand savings.
- Annual Energy Savings.

M&V Option

IPMVP Option A

Field Data Points

Post-Installation

Survey data

- Fixture count and wattages.
- Verified that all fixture specifications and quantities were consistent with the application.
- Determined how the lighting is controlled and recorded controller settings.
- Verified that all pre (existing) fixtures were removed.
- Determined what holidays the facility observes through the year.
- Determined if the lighting zones are disabled during the holidays.

Data Accuracy

Measurement	Sensor	Accuracy
Current	CTV-A 20A	±4.5%

Field Data Logging

The following table summarizes the quantities of lighting deployed loggers to monitor the retrofitted fixtures.

ECMs	Hobo (U12)	CTV-A 20A
1-9	14	50
Total	**14**	**50**

Data Analysis

There were three distinct space types monitored in this facility: An industrial production space that is cooled year round by a water-cooled chiller plant, office spaces that are heated and cooled with heat pumps, and office spaces that are heated with electric heat and not cooled. We conducted the following analysis for each of these three space types.

- Used the standard calculation template for estimating pre and post demand and energy consumption that incorporates the methodology described below.
- From survey data calculated the actual pre and post fixture kW.
- Weighted the time-series data according to connected load per control point. Methodology included in analysis worksheet.
- From time-series data determined the actual schedule of post operation.

$$\mathrm{LF(t)} = \frac{\sum_{\mathrm{i=1}}^{\mathrm{N_{Logged}}} \left(\mathrm{Current_{ControlPoint_i}} * \mathrm{ScaleFactor_i}\right)}{\sum_{\mathrm{i=1}}^{\mathrm{N_{Logged}}} \mathrm{kWControlPoint_i}}$$

$$\mathrm{kW_{Lighting}(t)} = \mathrm{LF(t)} * \sum_{\mathrm{i=1}}^{\mathrm{N_{ControlPoints}}} \mathrm{kWControlPoint_i}$$

Where

LF(t) = Lighting Load factor at time = t

$\mathrm{kWControlPoint_i}$ = connected load of control point i

$\mathrm{CurrentControlPoint_i}$ = logged current at control point i from time series data

$\mathrm{ScaleFactor_i}$ = Convert logged current to kW

NLogged = population of logged control points

NControlPoints = population of all control points

- Created separate schedules for weekdays and weekends using LF(t).
- Tabulated average operating hours by daytype (e.g. weekday and weekend).
- Extrapolated annual operating hours from the recorded hours of use by daytype.
- Generated the post load shape by plotting surveyed fixture kW against the actual schedule of post operation for each daytype.

- Calculated pre annual operating hours using the post-retrofit schedules by daytype and extrapolated to the full year.
- Calculated energy savings and compared to project application:

$$kWh_{savings} = (N_{Fixtures} * kW_{Fixture} * Hours)_{PRE} - (N_{Fixtures} * kW_{Fixture} * Hours)_{Post}$$

$$NCP\ kW_{savings} = (N_{Fixtures} * kW_{Fixture})_{PRE} - (N_{Fixtures} * kW_{Fixture})_{Post}$$

$$CP\ kW_{savings} = NCP\ kW_{savings}\ x\ CF$$

where:

$N_{Fixtures}$	= number of fixtures installed or replaced
$kW_{Fixture}$	= connected load per fixture
HOURS	= equivalent full load hours per fixture
NCP $kW_{savings}$	= non-coincident peak savings
CP $kW_{savings}$	= coincident peak savings
CF	= coincidence factor

- The savings with HVAC interactions are calculated from:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$
$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

where:

WHFe	= waste heat factor for energy
WHFd	= waste heat factor for demand

Verification and Quality Control

1. Visually inspected lighting logger data for consistent operation. Sorted by day type and removed invalid data.
2. Verified the post retrofit lighting fixture specifications and quantities were consistent with the application.
3. Verified that pre-retrofit lighting fixtures were removed from the project. Inspected storeroom for replacement lamps or fixtures.

Recording and Data Exchange Format

1. Hobo logger binary files
2. Excel spreadsheets

Results Summary

The following tables summarize the total estimated savings for the [redacted] lighting retrofit.

Table 1. Energy Savings and Realization Rates.

	Duke Savings	Realized Savings		Realization Rate	
		Lighting Only	Lighting and HVAC	Lighting Only	Lighting and HVAC
Energy (kWh)	7,901,837	6,995,380	7,360,561	89%	93%
Peak Demand (kW)	902	839	960	93%	106%
CP Demand (kW)	902	802	917	89%	102%

The energy and demand savings calculation summary is shown in **Error! Reference source not found.**. Demand savings details are shown in **Error! Reference source not found.**.

Table 2. Summary of Energy and Demand Savings Calculations.

Space Type	Base kW	EE kW	HRS	CF	Lighting Only			With HVAC Interactions			
					kWh savings	NCP kW	CP kW	Interaction Factors	kWh savings	NCP kW	CP kW
Office Heating & Cooling	223.7	68.6	8589	0.98	1,332,214	155.1	152.7	WHFe= 0.103 WHFd= 0.152	2,061,082	250.6	246.8
Office Heating Only	246.5	64.1	8500	0.96	1,550,441	182.4	175.1	WHFe= -0.154 WHFd= 0	1,845,789	256.7	246.4
Warehouse	767.3	265.7	8199	0.95	4,112,724	501.6	474.2	WHFe= 0.113 WHFd=0.194	6,403,149	837.3	791.5
Total	1237.5	398.3	8336	0.96	6,995,380	839.163869	802.0		7,360,561	959.96	917.10

- The office spaces that are heated and cooled are conditioned with heat pumps, the office spaces are that are heated only use electric heat. For both these space types, we used the NORESCO developed HVAC interaction factors for offices.

- The warehouse space of this facility is conditioned with a chiller plant. We used the NORESCO developed HVAC interaction factors for light industrial spaces with DX cooling and economizing.

The following figures show the average daily load shapes for each space type. When extrapolated to the year, the M&V annual operating hours ranged from 8,199 to 8,598, which range from 4.3% less than to 0.2% greater than the hours stated in the application.

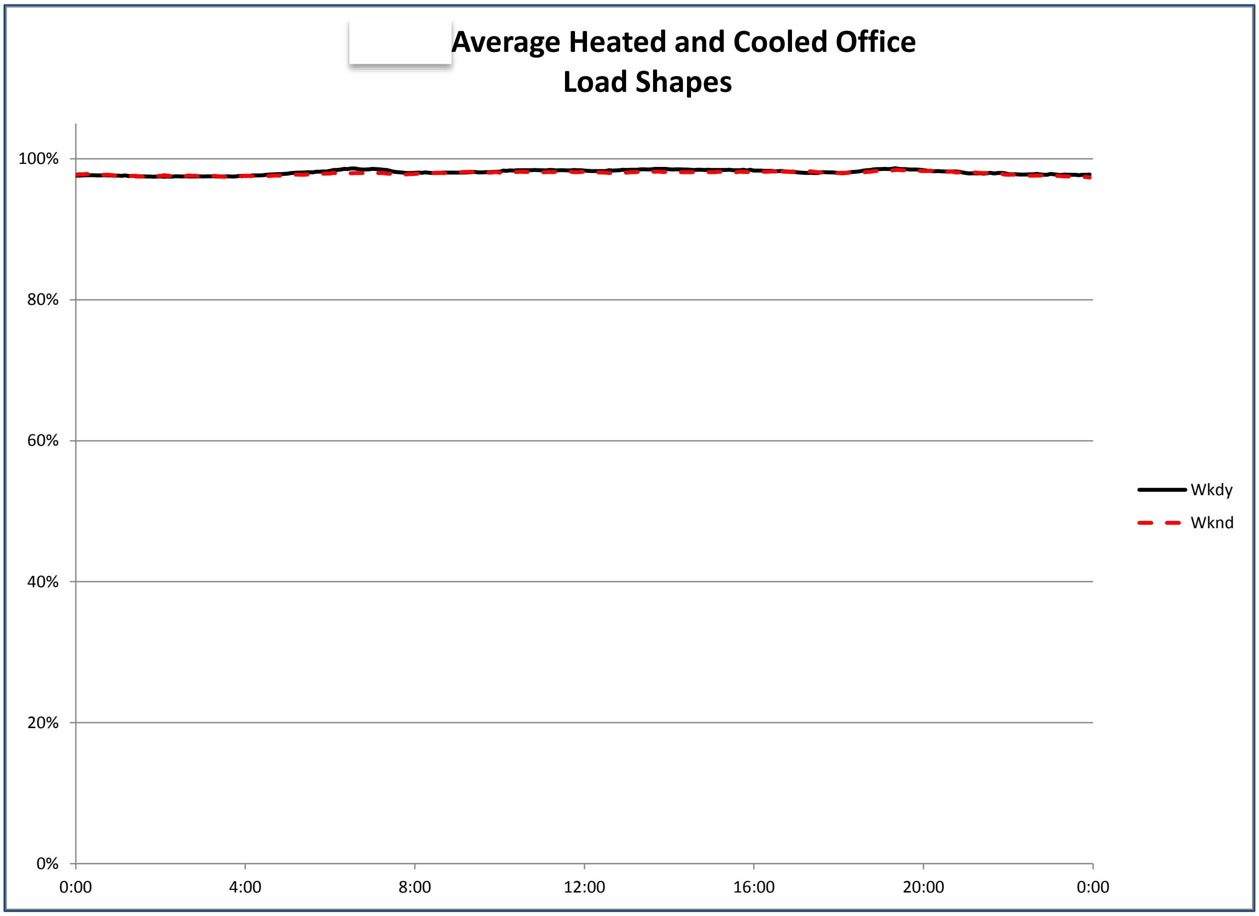

Figure 1: Average heated and cooled office load shapes.

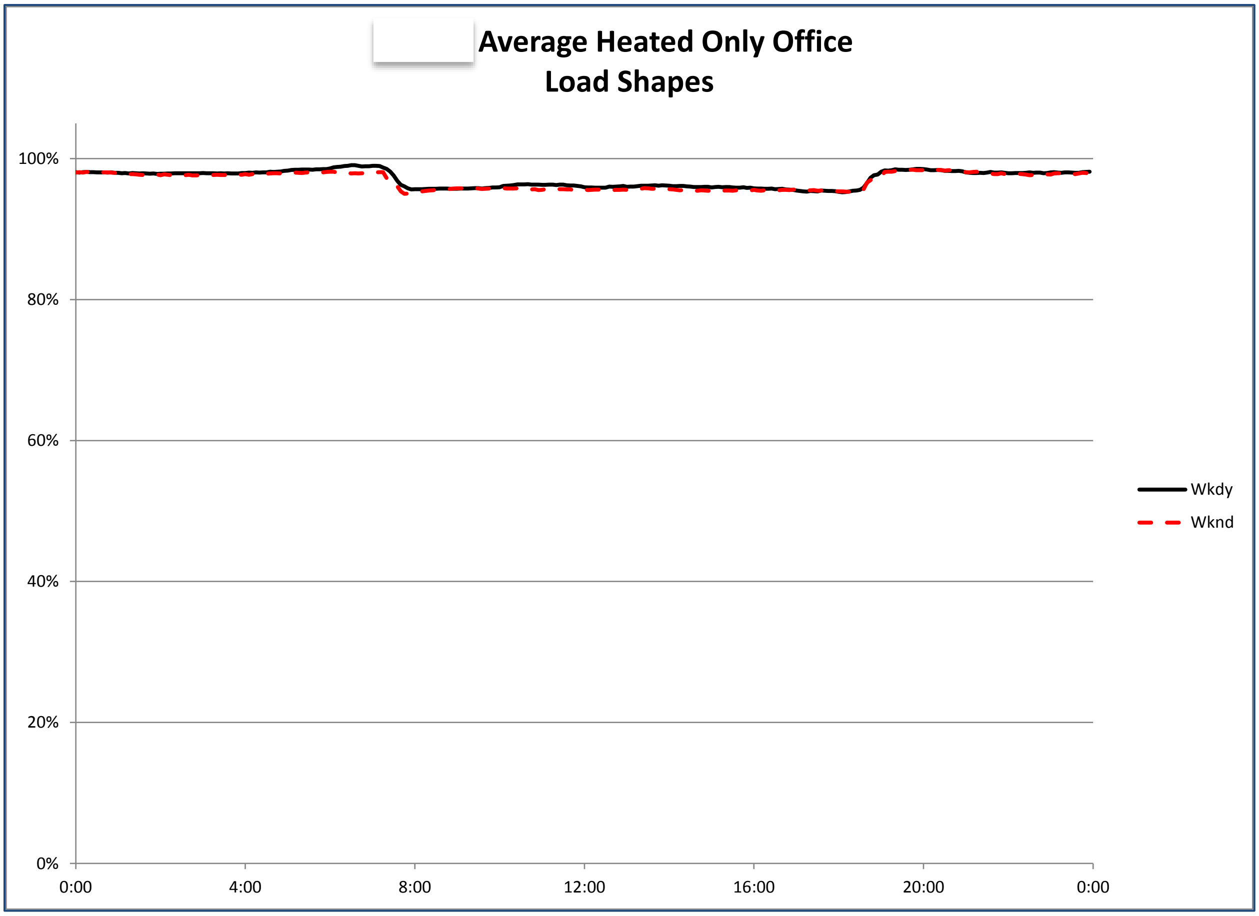

Figure 2: Average heated only office load shapes.

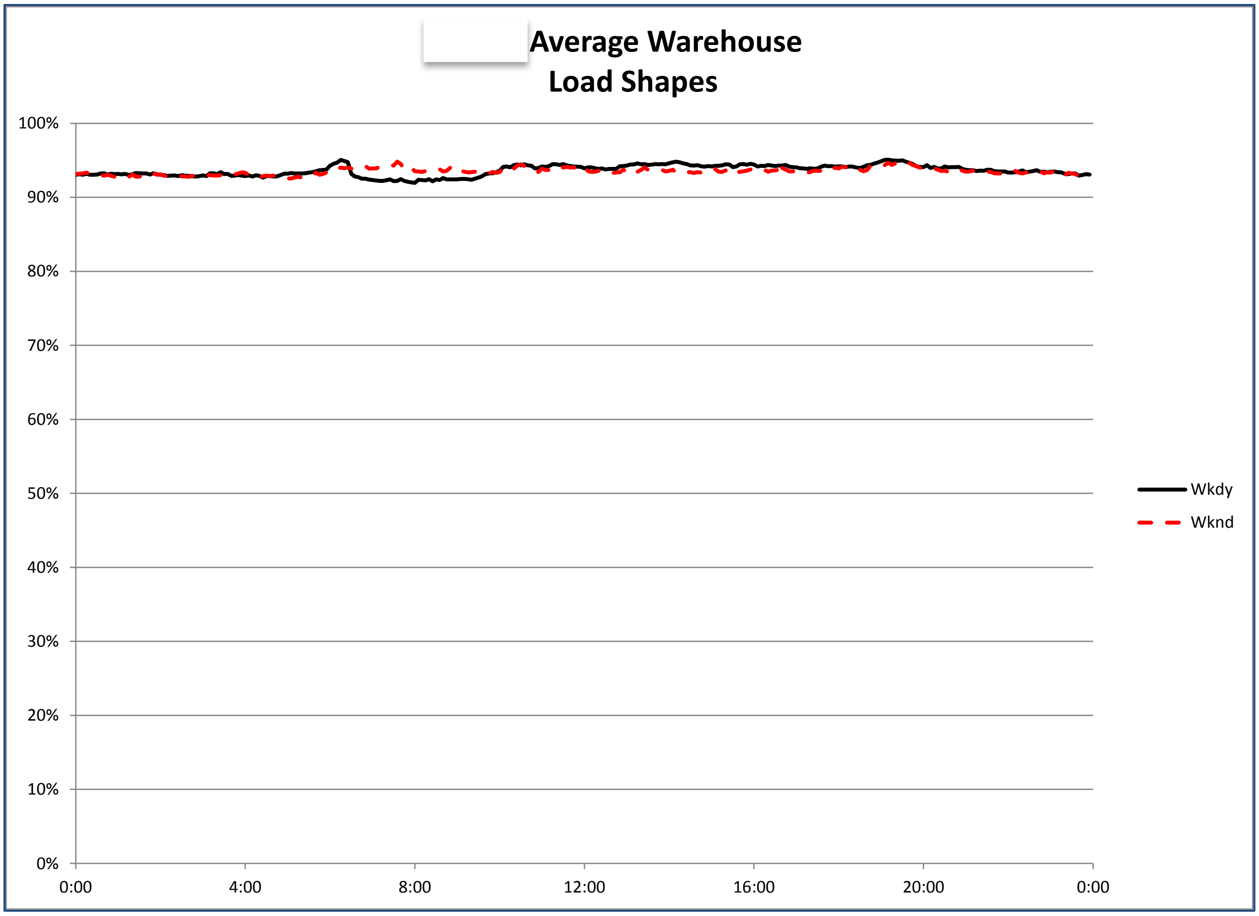

Figure 3: Average warehouse load shapes.

Table 3. Demand Savings Detail.

ECM	EE Technology						Base Technology				
	QTY	EE Fixture Type	W/ Fixture	Source	Cut Sheet W/ Fixture	kW	QTY	Base Fixture Type	W/ Fixture	Source	Connected kW
1	1	RST1802T832ENCCLSLUT, F28T8/XLSPX41ECO, GE232Max-Nultra	47.7	Spot measured	49	0.05	1	1) F48T12/HO 2) RST1802T832ENCCLSLUT, F28T8/XLSPX41ECO, GE232Max-Nultra	61.0	Appendix B	0.1
2	30	RST1802T832ENCCLSLUT, F28T8/XLSPX41ECO, GE232Max-Hultra	47.7	Spot measured	49	1.43	30	1) F96T12/HO/ES Mag STD 2) F96T12/HO/ES Electronic	90.7	Appendix B	2.7
3	1	RST1802T832ENCCLSLUT, F28T8/XLSPX41ECO, GE232Max-Nultra	47.7	Spot measured	49	0.05	1	1) F48T12/HO 2) RST1802T832ENCCLSLUT, F28T8/XLSPX41ECO, GE232Max-Nultra	81.0	Appendix B	0.1
4	69	RTR2402T832WNLUS, F28T8/XLSPX41ECO, GE232Max-NUltra	47.7	Spot measured	49	3.29	69	1) F48T12/ES Mag STD 2) F48T12/ES Electronic	67.3	Appendix B	4.6
5	112	RTR2202T817WNLUS, F17T8/SPX41/ECO, GE232Max-NUltra	32.0	Cut Sheet	32	3.58	112	1) F48T12/ES Mag STD 2) F48T12/ES Electronic	67.3	Appendix B	7.5
6	3236	RST1802T832ENCCLSLUT, F28T8/XLSPX41ECO, GE232Max-Nultra	47.7	Spot measured	49	154.34	3236	1) F96T12/HO/ES Mag STD 2) F96T12/HO/ES Electronic	191.0	Appendix B	618.1
7	144	RTR2402T832WNLUS, F28T8/XLSPX41ECO, GE232Max-Nultra	47.7	Spot measured	49	6.87	144	1) F48T12/ES Mag STD 2) F48T12/ES Electronic	134.7	Appendix B	19.4
8	2429	RST1804T832ENCCLSLUT, F28T8/XLSPX41ECO, GE432Max-Nultra	94.2	Spot measured	94	228.71	2429	1) F96T12/HO/ES Mag STD 2) F96T12/HO/ES Electronic	191.0	Appendix B	463.9
9	0	None	0	-	-	0	266	MH	455	Appendix B	121.0

Notes: SPC Apdx B – Appendix B 2013-14 Table of Standard Fixture Wattages. See http://www.aesc-inc.com/download/spc/2013SPCDocs/PGE/App%20B%20Standard%20Fixture%20Watts.pdf

Because magnetic ballasts are currently being phased out of the market place, we adjusted the base fixture wattage to account for this changing base line. The Duke Energy FES papers assume a 12 year measure life for linear fluorescent fixtures. We assumed that the baseline for the first quarter of the useful life would be a similar T12 fixture with a magnetic ballast. For the last three quarters of the useful life we assumed the baseline would be a similar T12 fixture with an electronic ballast. Table 4 shows the wattages that were used to determine the adjusted baseline. All of these wattages are from Appendix B. Table 5 below details the application annual savings over the measure life. For ECMs 1 and 3 there is not a similar fixture with an electronic ballast. For this reason we assumed that the last three quarters of the useful life baseline would be the fixture that was installed as part of this application. We chose this value because each of these ECMs only have one fixture and this approach offers conservative savings for these measures. The two fixtures used to determine the adjusted baseline are included in the Table 3 above.

Table 4. Adjusted Baseline Wattages.

Adjusted Baseline Calculations			
ECM	Magnetic Ballast W/ Fixture	Electronic Ballast W/ Fixture	Adjusted W/ Fixture
1	85	49	61.0
2	112	80	90.7
3	145	49	81.0
4	82	60	67.3
5	82	60	67.3
6	227	173	191.0
7	164	120	134.7
8	227	173	191.0

Table 5 Measure Life Annual Savings.

Measure Life	Lighting Only			With HVAC Interactions		
	kWh savings	NCP kW	CP kW	kWh savings	NCP kW	CP kW
Year 1	7,731,396	925	886	8,069,986	1,052	1,007
Year 2	7,731,396	925	886	8,069,986	1,052	1,007
Year 3	7,731,396	925	886	8,069,986	1,052	1,007
Year 4	7,731,396	925	886	8,069,986	1,052	1,007
Year 5	6,627,371	796	760	7,005,849	914	872
Year 6	6,627,371	796	760	7,005,849	914	872
Year 7	6,627,371	796	760	7,005,849	914	872
Year 8	6,627,371	796	760	7,005,849	914	872
Year 9	6,627,371	796	760	7,005,849	914	872
Year 10	6,627,371	796	760	7,005,849	914	872
Year 11	6,627,371	796	760	7,005,849	914	872
Year 12	6,627,371	796	760	7,005,849	914	872
Total	83,944,555	10,070	9,624	88,326,736	11,519	11,005

Measure Life Yearly Average	6,995,380	839	802	7,360,561	960	917

Application ID 13-1378419
Performance Contract Renovation
M&V Report

Prepared for
Duke Energy Carolinas

February 2015, Version 1.0
(Revised August 22, 2016)

Note: This project has been randomly selected from the list of applications for which incentive agreements have been authorized under Duke Energy's Smart $aver® Custom Incentive Program.

The M&V activities described here are undertaken by an independent third-party evaluator of the Smart $aver® Custom Incentive Program.

Findings and conclusions of these activities shall have absolutely no impact on the agreed upon incentive between Duke Energy and [redacted]

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On August 22, 2016 the Duke Energy projected savings in this report were corrected by Cadmus to correspond to Duke Energy expected savings as found in the Duke Energy program tracking database.

Introduction

This report addresses measurement and verification (M&V) activities for the [redacted] custom program application. The application covers various HVAC renovations at 7 different buildings.

[Redacted] Building #1

- Retrofit of the existing pneumatic controls to direct digital controls, and installation of new VFDs on AHUs serving the [redacted] building.
- Existing Equipment includes Central Station AHU with supply and return fans with inlet guide vanes. Existing EMS is a combination of legacy DDC and pneumatic controls.
- New equipment includes the installation of VFDs and new inverter duty motors on supply and return fans. Existing pneumatic controls to be replaced and integrated into existing DDC controls to connect to Campus BAS.

[Redacted] Building #2

- Retrofit of the existing pneumatic controls to direct digital controls, AHU VFD, and retrofit of the chiller plant serving the [redacted] building.
- Existing Equipment includes (4) Central Station AHU with supply fans with Inlet guide vanes. Existing EMS is a combination of legacy DDC and pneumatic controls. Secondary CHW pumping is constant volume.
- New equipment includes new AHU's with VFDs. Existing pneumatic controls to be replaced and integrated into existing DDC controls to connect to Campus BAS. VFDS are to be installed on secondary CHW pumps.

[Redacted] Building #3

- Retrofit of the existing pneumatic controls to direct digital controls serving the [redacted] building.
- Existing Equipment includes a central Station AHU. Existing EMS is a combination of legacy DDC and pneumatic controls.
- Existing pneumatic controls to be replaced and integrated into existing DDC controls to connect to Campus BAS.

[Redacted] Building #4

- Retrofit of the existing pneumatic controls to direct digital control serving the [redacted] building.
- Existing Equipment includes a central Station DD VAV AHU and three RTU's,

- Existing Equipment includes a central Station AHU. Existing EMS is a combination of legacy DDC and pneumatic controls.
- Existing pneumatic controls to be replaced and integrated into existing DDC controls to connect to Campus BAS.
- Existing building chilled water system was shut down and chilled water system was tied in to the adjacent [redacted] building chilled water plant.

[Redacted] Building #5

- Retrofit of the existing pneumatic controls to direct digital controls serving the [redacted] building.
- Existing Equipment includes a central Station AHU. Existing EMS is a combination of legacy DDC and pneumatic controls.
- Existing pneumatic controls to be replaced and integrated into existing DDC controls to connect to Campus BAS.

[Redacted] Building #6

- Retrofit of the existing pneumatic controls to direct digital controls, AHU VFDs, and retrofit of the chiller plant serving the [redacted] building.
- Existing Equipment includes (7) VAV AHU's with Inlet guide vanes. Existing EMS is a combination of legacy DDC and pneumatic controls. Secondary CHW pumping is constant volume.
- New equipment includes new VFDs on AHU supply fans. Existing pneumatic controls to be replaced and integrated into existing DDC controls to connect to Campus BAS. VFDS are to be installed on secondary CHW pumps.

[Redacted] Plant #7

- Modify chilled water pumping system to be variable and integrate chiller plant optimization program.
- Existing equipment includes (1) 300 ton, (2) 1000 ton and (1) 2000 ton chillers and (2) 300 Bhp hot water boilers.
- Optimize chiller plant with continuous monitoring and adjustment for chiller plant equipment. Provide eight (8) VFDs for the primary chilled water and condenser water pumps.

Goals and Objectives

Pre-and post-retrofit energy models of the building's energy use were created to determine the energy and power reduction achieved by the control system upgrades.

The projected savings goals identified in the application were:

	APPLICATION		DUKE PROJECTIONS		
Facility	**Proposed Annual kWh savings**	**Proposed Summer Peak kW savings**	**Expected Annual kWh savings**	**Expected Summer Coincident peak kW savings**	**Expected Summer Non-coincident peak kW savings**
Building #1	1,212,683	72	1,212,681	67	111
Building #2	535,039	937	535,042	93	95
Building #3	419,256	94	419,254	74	139
Building #4	600,766	61	613,500	61	84
Building #5	294,638	17	294,639	14	31
Building #6	317,167	40	317,164	50	51
Plant #7	1,087,795	79	1,210,414	56	178
Total	**4,467,344**	**1,300**	**4,602,694**	**414**	**689**

The objective of this M&V project was to verify the actual:

- Annual gross electric energy (kWh) savings
- Building peak demand (kW) savings
- Coincident peak demand (kW) savings
- Energy, demand and coincident demand Realization Rates

Project Contacts

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Customer Contact	Redacted		

Site Locations/ECM’s

Address
Redacted

Data Products and Project Output

- Energy consumption pre- and post-retrofit for the entire facility
- Annual energy savings
- Peak demand savings
- Coincident peak demand savings.

M&V Option

IPMVP Option A & D

M&V Implementation

This survey and data collection was for post-retrofit only, and due to the magnitude of the implemented ECMs, was performed on a sample of the buildings listed in the introduction. The buildings that were evaluated are [redacted] Bldg #1, [redacted] Bldg #4, and the [redacted] Plant #7. These are the three largest projects in the original application, and represent about 73% of the total claimed savings. Tasks carried out during the M&V included the following.

- Conducted an interview with the building contact.
- Obtained copies of building floor plans for evaluated buildings.
- For buildings being evaluated, collected billing data (monthly kWh and demand) for January 2011 - present.
- For buildings being evaluated, confirmed trending capability for the points listed in the Field Data Logging section.
- Identified HVAC equipment currently on the new digital control system and collected nameplate data.
- Verified that equipment moved to the new control system is operating properly.
- Obtained pre-retrofit and post-retrofit sequences of operation for all controlled equipment.
- Deployed loggers and established trend logs to monitor operation of supply fans, compressors, economizers, CHW pumps, CO2 levels, and outdoor air temperature and relative humidity.
- Trended EMS data and deployed loggers for three weeks.
- Constructed and calibrated the building energy model.
- Evaluated the energy impacts of the building retrofit in the energy model.

Data Accuracy

Measurement	Sensor	Accuracy	Notes
Current	Magnelab CT	±1%	Recorded load must be >10% of CT rating
Temperature	Onset Temp/RH	±0.36°F	
True electric power	ElitePro	±1%	
EMS trend points	Various		EMS sensor accuracy not known

Field Data Points

[Redacted] Building #1 (Option A)

One-time measurements for all equipment logged (to check and validate logger/trend data)

- (2) 200 HP AHU supply fan volts, amps, kW, VFD speed and power factor
- (2) 60 HP AHU return fan volts, amps, kW, VFD speed and power factor

[Redacted] Building #4 (Option D)

The following survey data was collected:

- Floor plans, lighting plans, and mechanical showing VAV boxes.
- Utility bills (kWh and kW) from January 2011 to present.
- Nameplate data and quantity for all HVAC equipment.
- Pre-retrofit and post-retrofit sequences of operation for all controlled equipment. Complete the attached HVAC Operating Information tables.
- All other information in the Survey-IT data form. This form includes detailed information about all building systems, including:
    - Building wall, window and floor area
    - Space types and uses
    - HVAC zoning
    - Occupancy schedules and operations (daily, weekly, annually, holidays)
    - Lighting loads and schedules
    - Equipment loads and schedules
    - Temperature setpoints/schedules, Energy Management Systems
    - HVAC system controls
    - Fan and pump operation

- Shading and blinds
- Chillers, cooling towers, boilers, central air handlers, and water heating
- Building envelope, including windows, walls, areas, and construction types

[Redacted] Plant #7 (Option A)

The following survey data was obtained for all equipment logged in the Chiller Plant:

- (2) 2000 ton cooling tower make/model/serial number/VFD Info.
- (1) 300 ton chiller make/model/serial number
- (2) 1000 ton chiller make/model/serial number
- (1) 2000 ton chiller make/model/serial number
- (1) 10 HP Primary CHW pump make/model/serial number
- (2) 40 HP Primary CHW pump make/model/serial number
- (1) 60 HP Primary CHW pump make/model/serial number
- (3) 75 HP Secondary CHW pump make/model/serial number/ VFD Info

The following one-time measurements were taken for all equipment logged (to check and validate logger/trend data)

- (2) 2000 cooling tower volts, amps, kW and power factor, and VFD speed(s). Note number of fans running at the time of the measurements.
- (1) 300 ton chiller volts, amps, kW and power factor
- (2) 1000 ton chiller volts, amps, kW and power factor
- (1) 2000 ton chiller volts, amps, kW and power factor
- (1) 10 HP Primary CHW pump volts, amps, kW, and power factor
- (2) 40 HP Primary CHW pump volts, amps, kW, and power factor
- (1) 60 HP Primary CHW HP pump volts, amps, kW, and power factor
- (3) 75 HP Secondary CHW pump VFD speed, volts, amps, kW, and power factor

Field Data Logging

- Installed data loggers to log the following data points in 5 minute intervals.
- Where BAS was capable of trending the following, trends were set up in place of data loggers. Since kW was not available at the BAS, kW, amperage, and voltage was logged on each type of equipment and trends were set up for VFD speed and static pressure on all equipment. Data was collected for 3 weeks. Unfortunately, some of the trends that were set up by the facility staff were logged at different time periods, which reduced their usefulness during the analysis.

[Redacted] Building #1 (Option A)

1. (2) 200 HP Supply Fan kW and VFD speed(s) and static pressure
    a. Note that the data logger for Supply Fan #1 failed and the data was corrupted, however that fan tracks Supply Fan #2 and so results were not compromised.
2. (2) 60 HP Return Fan kW and VFD speed(s)

[Redacted] Building #4 (Option D)

1. No data logging was performed. Site visit included collecting building information such as nameplate data and building geometry.

[Redacted] Plant #7 (Option A)

1. (2) 2000 ton cooling tower kW and VFD speed(s) (4-25 HP Fans each)
2. (1) 300 ton chiller kW and VFD speed(s)
3. (2) 1000 ton chiller kW and VFD speed(s)
4. (1) 2000 ton chiller kW and VFD speed(s)
5. (1) 10 HP Primary CHW pump kW and GPM
6. (2) 40 HP Primary CHW pump kW and GPM
7. (1) 60 HP Primary CHW pump kW and GPM
8. (3) 75 HP Secondary CHW pump kW, GPM, and VFD speed(s)
9. OA Temperature and RH
10. Chilled Water Supply Temperature (Per chiller and system)
11. Chilled Water Return Temperature (Per chiller and system)
12. Condenser Water Supply Temperature (Per chiller and system)
13. Condenser Water Return Temperature (Per chiller and system)
14. CHW flow rate (Per chiller and system)
15. CW flow rate (Per chiller and system)
16. OA Temperature and RH

Note: Unfortunately, not all points were logged at the same time and interval which created some difficulty with data analysis.

- **Outdoor Air**

1. BAS trends were set up to record OA temperature and RH, Logged for 3 weeks**.**

Logger Table

The following table summarizes all logging equipment that was used to accurately measure the above noted ECM's:

ECM	Elite-Pro	Hobo Energy Logger Pro	Magnelab CT's	24" RoCoil
SF-1 (Building #1)	1		(3) 500 A	
SF-2 (Building #1)	1		(3) 500 A	
RF-1 (Building #1)	1		(3) 100 A	
RF-2 (Building #1)	1		(3) 100 A	
300 ton Chiller (Plant #7)	1		(3) 500 A	
1000 ton Chiller (Plant #7)	1		(3) 1000 A	
2000 ton Chiller (Plant #7)	1			(3) 2100 A
10 HP Primary CHW Pump (Plant #7)		1	(1) 20 A	
(2) 40 HP Primary CHW Pump (Plant #7)		2	(2) 50 A	
60 HP Primary CHW Pump (Plant #7)		1	(1) 100 A	
(3) 75 HP Secondary CHW Pump (Plant #7)	3		(9) 100 A	
Total	**10**	**4**	**31**	**3**

Data Analysis

Each building in this study implemented a different combination of ECMs. In general, there are 3 different ECMs implemented in the various buildings. These ECMs are as follows:

- Installation of new VFDs for supply and return fans on AHUs serving the building. VFDs replaced inlet guide vane flow control.
- Retrofit of the existing pneumatic controls to direct digital controls. Upgraded controls allowed more sophisticated control strategies such as:
  - HVAC operating schedule adjusted from 24/7 operation to off at night.
  - Space temperature setpoints adjusted from constant at all times to adjustable with a night setback.
  - Economizer operation re-established
  - Supply air temperature reset strategy
- [Redacted] Plant #7 modification. Generally this means an old inefficient chiller was removed and the chilled water system was connected to a modern, more efficient chilled water system ([redacted] Building #4).

Due to the magnitude of this M&V study, the savings for every ECM in each building was not calculated. Instead, representative buildings were chosen and the ECM savings were calculated for those buildings only. The ECM realization rate was then applied to each of the other buildings with that ECM. Specifically, the "VFD" ECM was calculated at the [redacted] building #1, and the "controls" and "[redacted] plant #7" ECMs were calculated at the [redacted] building #4. The [redacted] plant #7 is unique and was analyzed separately.

VFD ECM Analysis

Time series kW data was obtained for each VFD installed at the [redacted] building #1. The VFD installed on the AHU fans is used to more efficiently reduce the fan flow rate. Prior to installing the VFD, the fan would run at full speed with variable inlet vane flow control.

To estimate savings, the first step was to develop an approximation of the annual energy use in the post-retrofit case. Because only three weeks of actual data was monitored, that data needed to be extrapolated to a full year. This was accomplished by developing a relationship between fan power and outside air temperature.

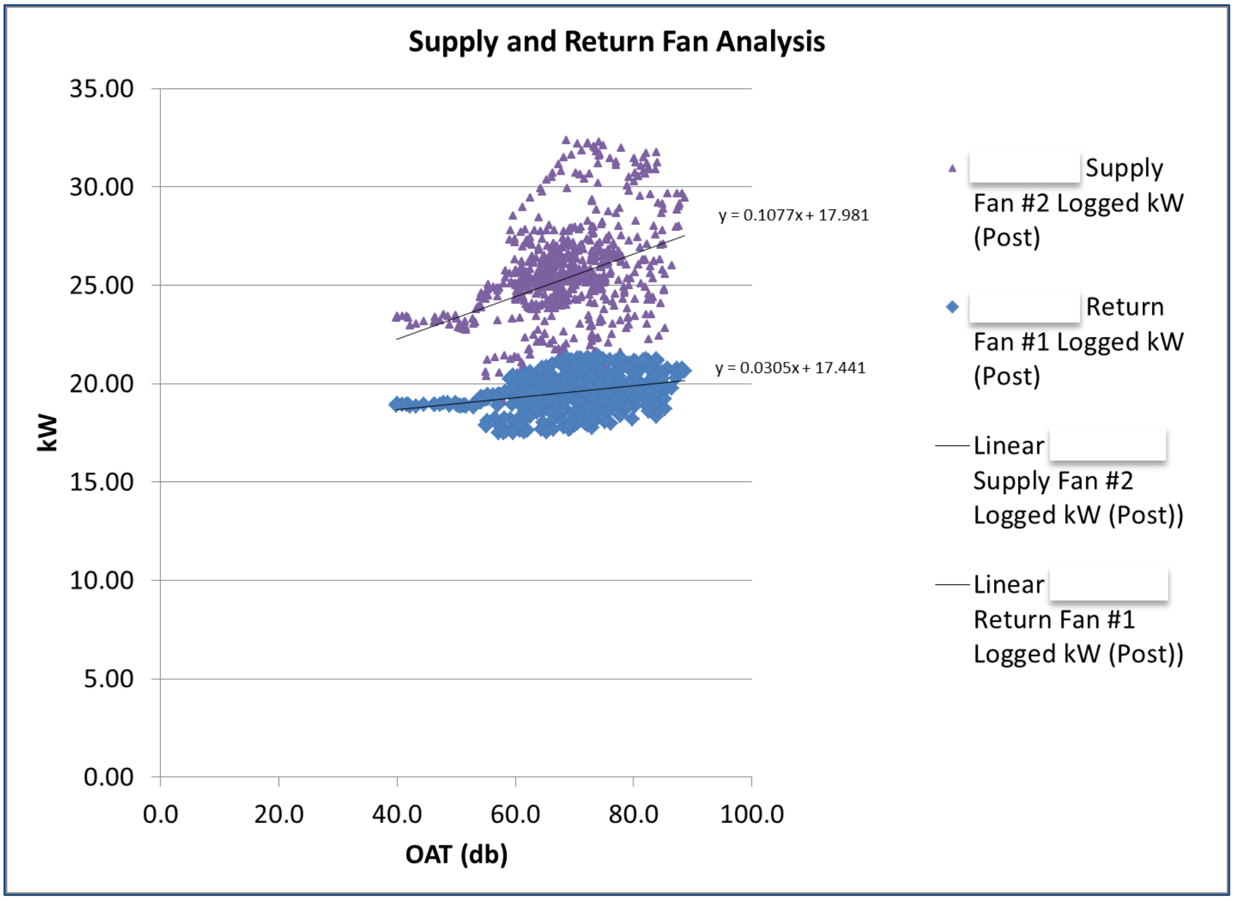

Figure 1. Supply and Return Fan Analysis

Figure 1 above shows the logged supply and return fan power plotted against outside air temperature. The linear equations displayed are an approximation of the relationship between outside air temperature and fan power. Looking at Figure 1, the data appears to be somewhat scattered and the relationship between kW and OAT is not very strong. In an attempt to finder a stronger relationship, the data was sorted, viewed in a few different formats, and filtered. Figure 2 and Figure 3 shown below offer a few different views of the supply fan data.

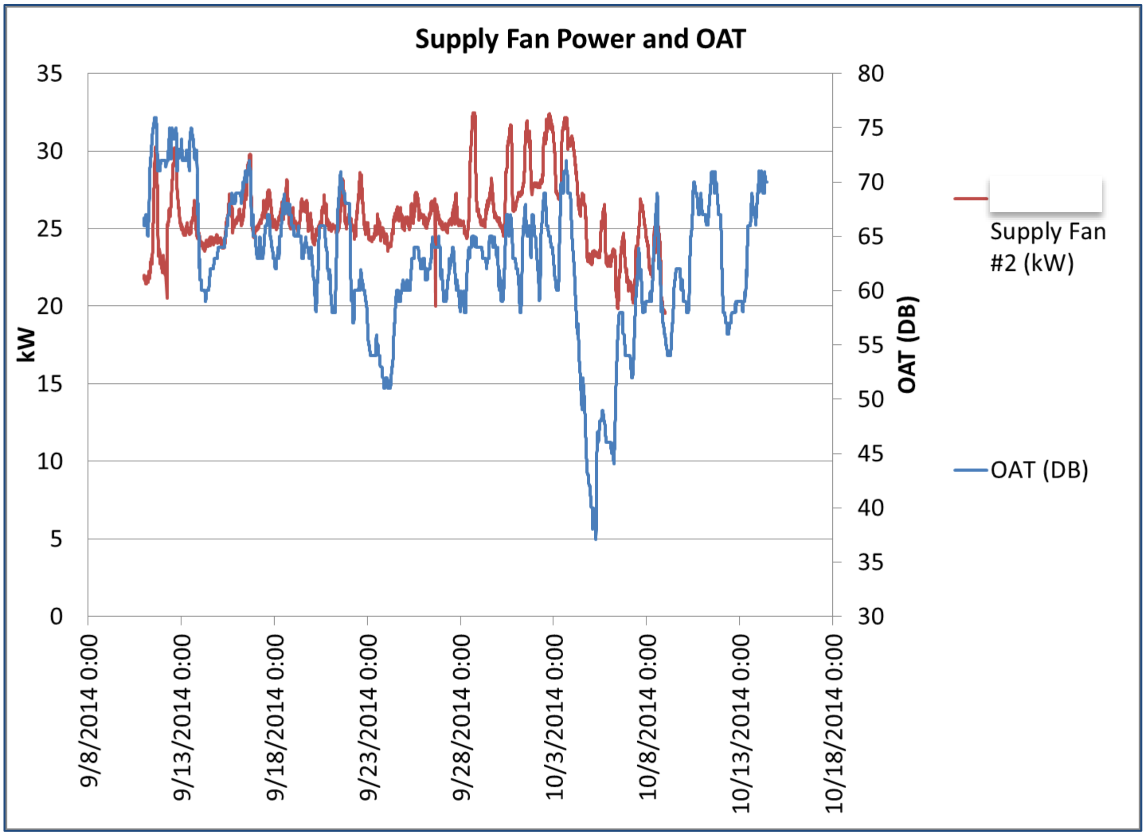

Figure 2. Fan power and OAT

Figure 2 shown above is the supply fan power and outside air temperature (OAT) during the months of September and October 2014. It is evident that there is a relationship between the two; however it is somewhat inconsistent.

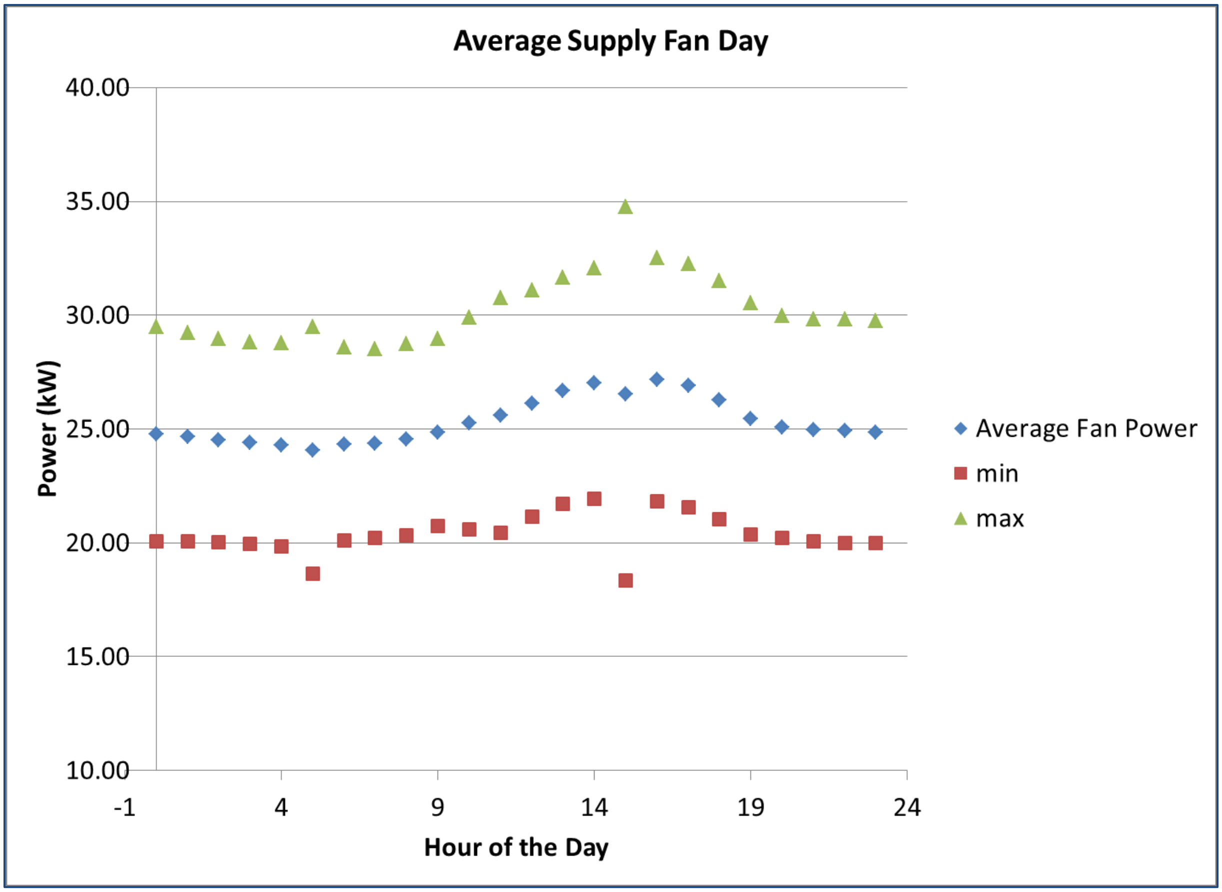

Figure 3. Average Supply Fan Day

Figure 3 shows the average supply fan power during each hour of the day along with the minimum and maximum values during the 6 week monitoring period. It is evident that fan power does follow a pattern during the day peaking around hour 15 (3pm), however the standard deviation is so large as to preclude developing any reasonable relationship. One conclusion to be drawn from Figure 2 and Figure 3 is that there may be a controls issue present in the building which is worth investigating.

Unfortunately, there was simply no way to come up with an improved fan power estimate and so the equations in Figure 1 were used as the best available option. The estimated annual energy use by each of the fans for the post-retrofit case was approximated by applying the linear regression equations in Figure 1 to the hourly average OAT values in a TMY weather file for Charlotte, NC.

Once the post-retrofit fan energy was calculated, the next step was to calculate the pre-retrofit fan energy.

The first step in determining the pre-retrofit fan energy is to determine the power that the fan would draw at full speed. Unfortunately, it was not possible to take a one-time, full-speed power measurement to estimate the full flow power consumption. Instead, kW was logged during the same time period as VFD speed %. By plotting power against speed, a relationship between kW and fan speed was approximated.

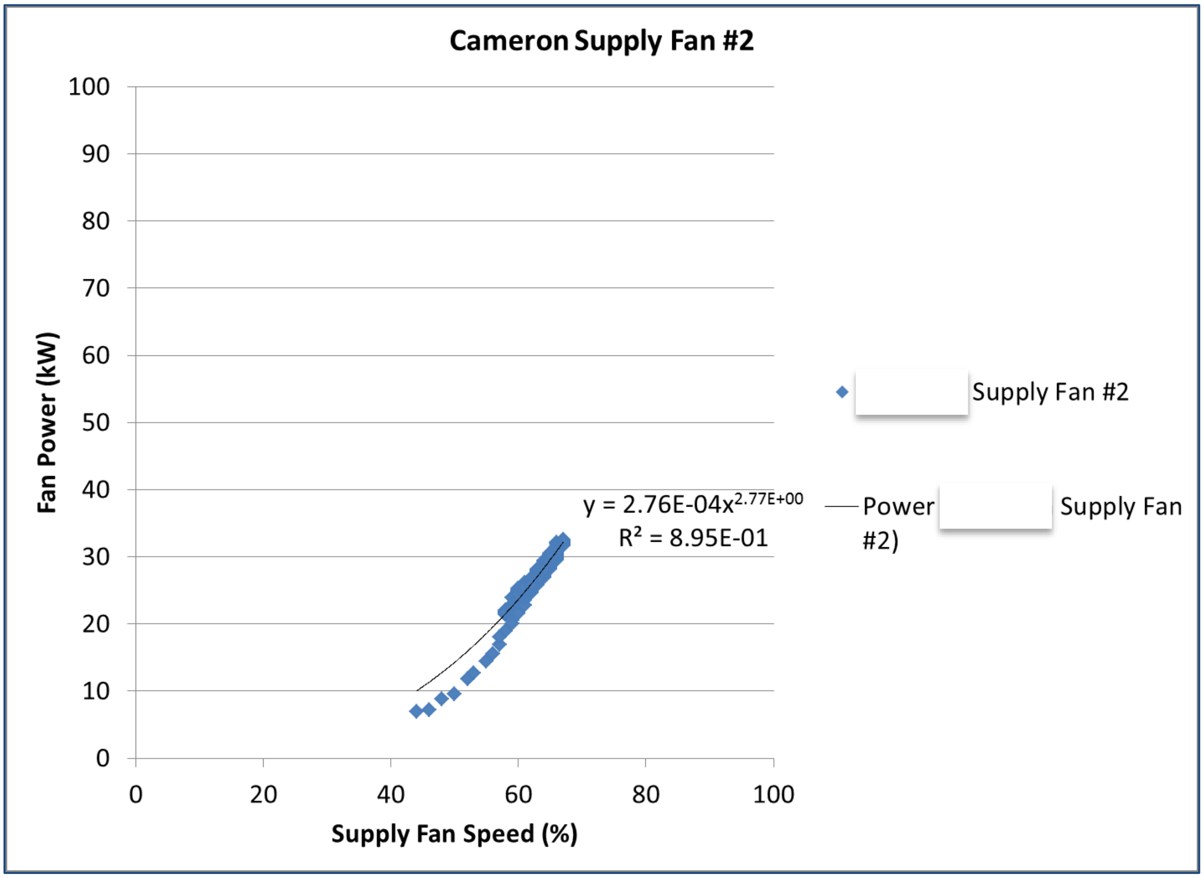

Figure 4. Supply Fan Power vs Speed

Figure 4 above shows the relationship between supply fan power and speed. A curve fit is displayed on the plot which allows extrapolation of the data. Extrapolating the fan speed to 100% provides a reasonable approximation of the maximum fan power which can then be used to calculate the pre-case fan curve with variable inlet vanes.

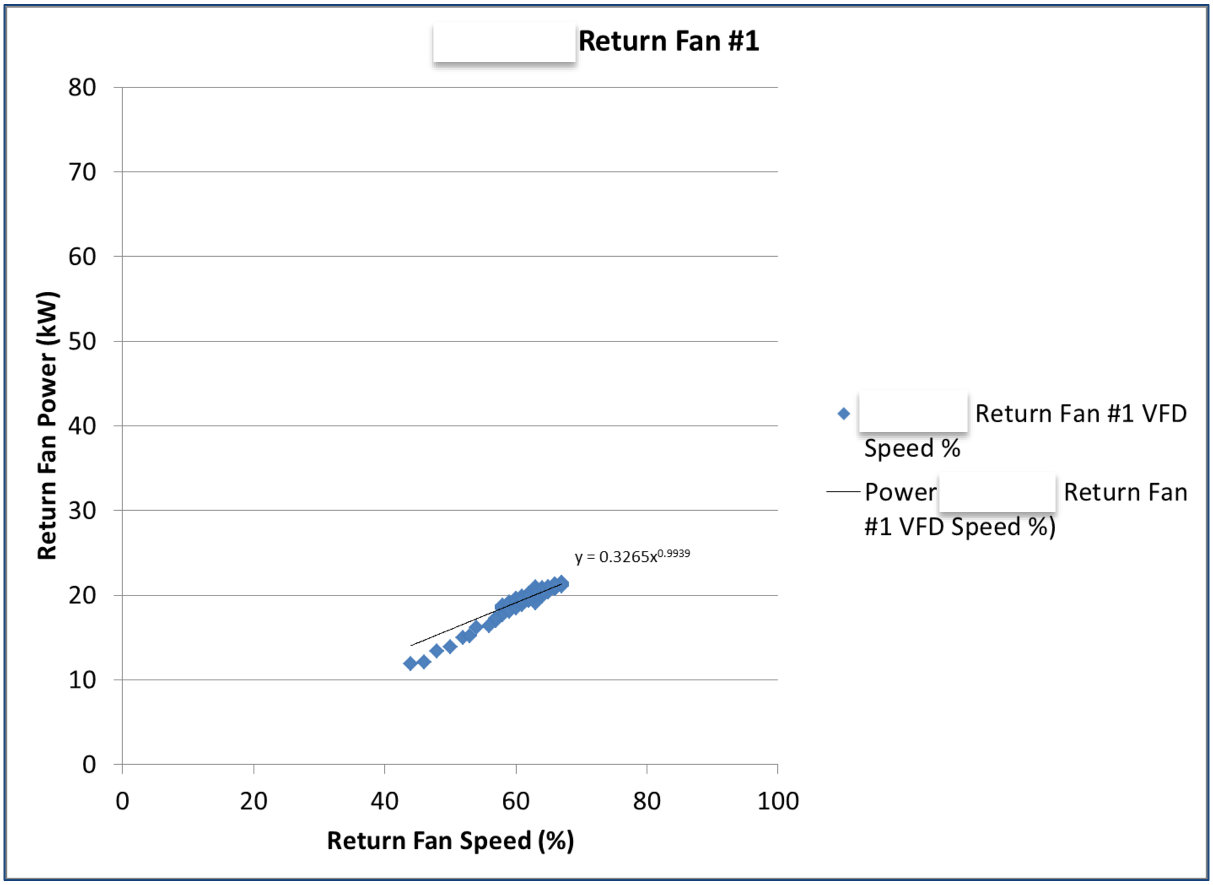

Figure 5. Return Fan Power vs Speed

Figure 5 above shows the same power vs speed relationship as Figure 4 but for the return fan. This relationship was used to estimate maximum return fan power.

The fraction of the maximum kW was calculated at each interval, and the fraction of full flow was calculated assuming the appropriate relationship shown below:

Determine post-retrofit flowrate:

Using the VFD power ratio relationship, estimated the post-retrofit (VFD) flow ratio (*f*) using the following basic equation:

$$H = \frac{a + b * f + d * f^3}{\eta_{drive}}$$

Where:

H = ratio of fan power at flow ratio *f* to the maximum fan power

$$= \frac{kW(f)}{kW_{\max}}$$

$$a = \left(\frac{P_0}{2}\right)^{1.5}$$

$$b = P_0 * (1 - a)$$

$$d = 1 - a - b$$

$$\eta_{drive} = VSD\ efficiency$$

P_0 = pressure offset ratio

f = flow ratio

$$f = \frac{Flow}{Flow_{design}}$$

The pressure offset ratio is defined as the ratio of the static pressure set point to the static pressure rise at the design flow rate. The pressure offset ratio is used to account for the energy required to maintain system static pressure over all flow rate ranges. Typical values range from 0.3 to 0.4.

The above equations were used to develop a relationship for f, the flow ratio, as a function of the power ratio. Once the flow ratio was determined, the pre-retrofit power ratio was calculated using the equation below:

For variable inlet vane control:

$$H = a + \frac{f}{b + c * f^2}$$

Where:

a = 0.354

b $= \dfrac{2 - p_0}{0.646}$

c $= \dfrac{p_0 - 1}{0.646}$

The result of this analysis is show in Figure 6 below.

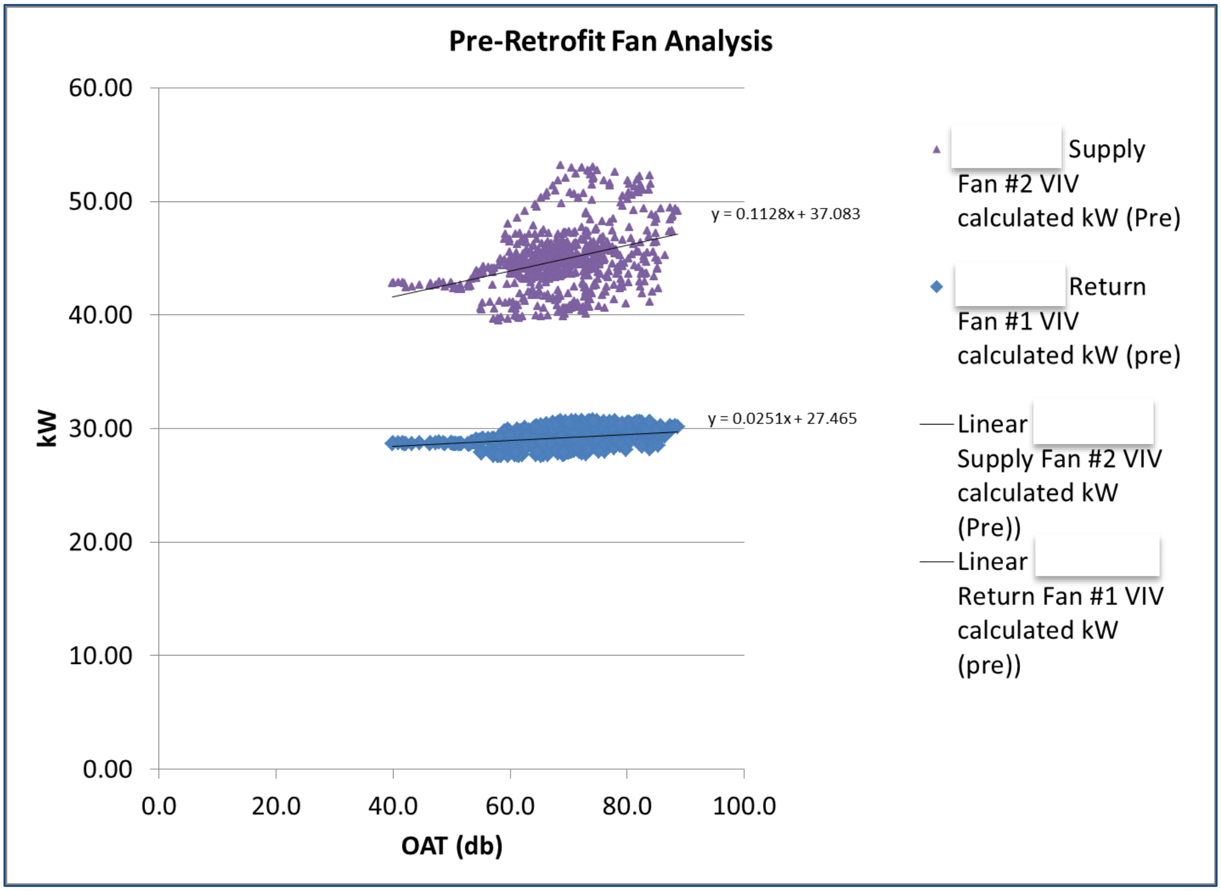

Figure 6. Pre-Retrofit Fan Analysis

From this point, the pre-retrofit fan energy calculation was performed in the same manner as the post-retrofit case. The relationship between fan power and outside air temperature was applied to the outside air temperatures from a TMY weather file to achieve an estimated annual energy use for the supply and return fans.

The last step in estimating the energy savings from this ECM is to simply calculate the difference between the pre-retrofit and post-retrofit annual energy use. The final numbers from this analysis along with realization rates are presented in the results section of this report.

Controls Upgrade Analysis

The [redacted] building #4 was chosen to perform the controls upgrade analysis. NORESCO staff surveyed the [redacted] building #4 and collected all of the information necessary to simulate the building. Once all of the necessary data was collected, an eQUEST model was generated with pre-retrofit operational sequences.

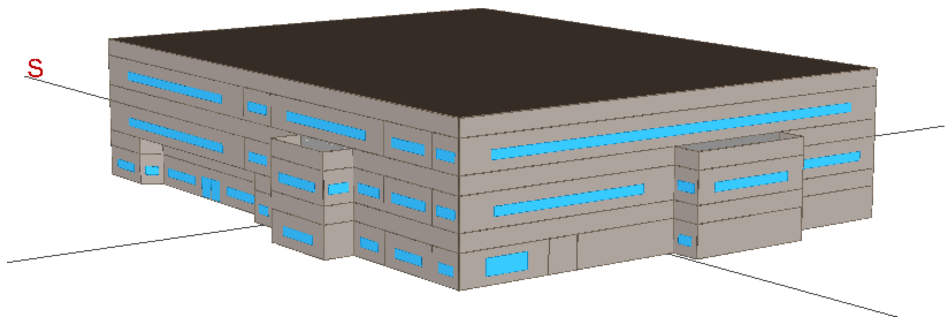

Figure 7. eQuest building representation

The energy model was then calibrated to pre-retrofit utility bills in order to achieve the most accurate pre-retrofit simulation possible. In order to match the energy model results to past utility bills, only those parameters that are not known with a high level of certainty were modified. These parameters included plug loads, certain schedules, and infiltration, among others. Any parameters which were directly affected by the retrofit and have been explicitly monitored during post-retrofit data collection were NOT modified during model calibration.

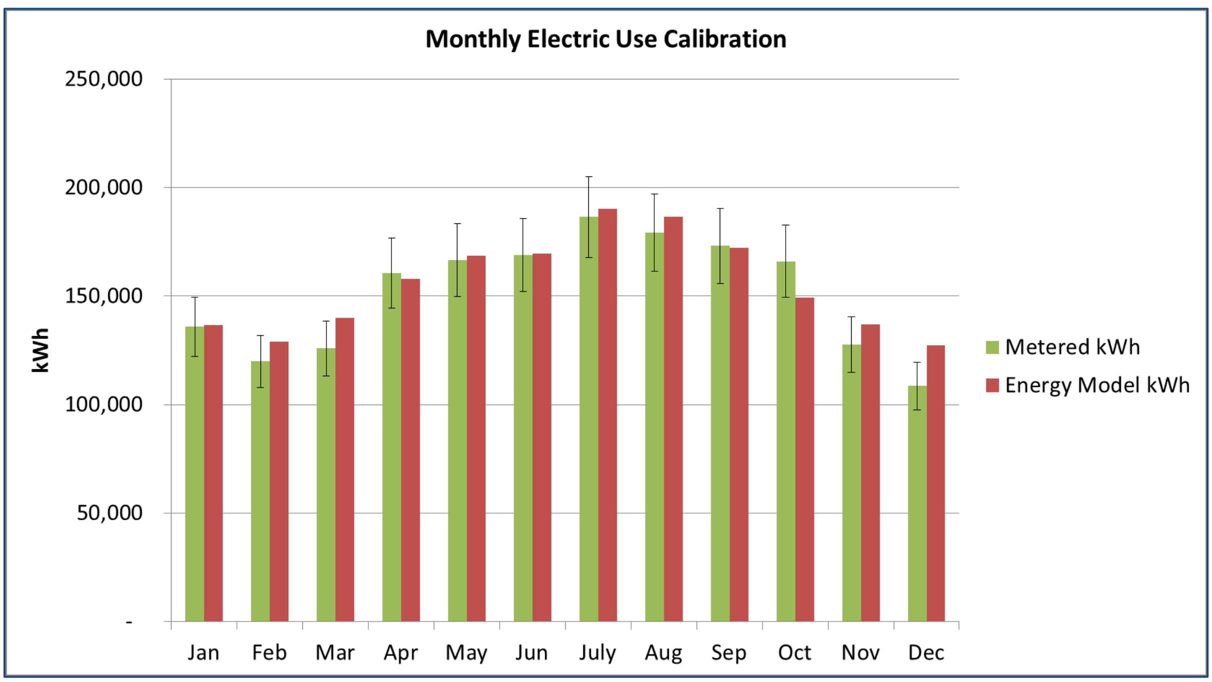

Figure 8. Energy Model Calibration

Figure 8 shown above is a comparison of the actual monthly electric consumption of the building in 2013 to the modeled consumption for each month of that year. 10% error bars are shown on the Metered kWh columns to visually represent the accuracy of the calibration. Generally, the monthly energy model consumption is within the 10% margin with only a couple of months outside that range. The annual energy use predicted by the energy model is within

2.5% of the actual metered energy. This indicates a relatively accurate energy model of the pre-retrofit case.

Once the pre-retrofit model was established, NORESCO revised the model with the post-retrofit changes in sequences of operations. The changes in sequences of operations are listed below:

- HVAC operating schedule adjusted from 24/7 operation to off at night.
- Space temperature set points adjusted from 70.2F at all times to 71 heating, 75 cooling with a night setback.
- Economizer operation re-established
- Supply air temperature reset controls

With these changes made, the model was run again to determine estimated annual post-retrofit energy consumption from the "controls upgrade" ECM. Comparison of the post-retrofit model output with the pre-retrofit output provided an estimate of the annual energy savings.

[Redacted] Plant #7 Modification Analysis
Using the same calibrated energy model for the [redacted] building #4, a third model run was simulated with the following change to model the decommissioning of the chiller in this building:

- Chiller operation changed from constant speed to variable speed and efficiency improved by approximately 25% to match the efficiency of the cooling plant in the adjacent McEniry building.

The results of that simulation were compared with that of the previous "controls upgrade" ECM to determine the savings from the "[redacted] plant #7 modification" ECM.

[Redacted] Plant #7 (Option A analysis)

- **General**

1. Converted time series data on logged equipment into post average load shapes by day-type.
2. Generated pre-retrofit model from performance curves and post retrofit consumption field data.
3. Developed pre/post regression model of total daily kWh as a function of average outdoor drybulb temperature.
4. Extrapolated pre/post total daily kWh to annual kWh using annual weather data (TMY3).
5. Estimated annual energy savings as the difference in the annual totals of pre- and post-kWh.
6. Estimated peak demand savings by subtracting pre/post time series data during peak ambient temperatures.

7. Calculated coincident peak savings by subtracting pre/post peak kW values at July 17, 3-4 pm local time, the coincident peak hour.

- **Pumps**

1. Generated pump kW vs. OAT regression for logged data (post conditions)
2. Generated pump kW vs. OAT regression for the Pre conditions by assuming the pumps will consume a constant amount of power if energized. OAT values remain the same as in the post conditions.
3. Applied equations above to TMY3 data processed into average drybulb temperature for each day of the year.

Time series kW data was obtained for each VFD installed at the [redacted] plant #7. The VFDs installed on the primary chilled water pumps (PCHWP) and condenser water pumps (CWP) are used to reduce the pump flow rate. Prior to installing the VFDs, it was assumed that the pumps would run at full speed with a throttled triple duty valve for flow control.

The primary chilled water pumps and condenser water pumps are dedicated, one set per chiller. During the logging period, only chiller 4 ran. Therefore, logged data was used only for the calculations for PCHWP-4 and CWP- 4. Pump savings for the other pump combinations were based on the results for the Chiller 4 pumps.

Figure 9 and Figure 10 show average hourly logged kW regressed against Outside Air Temperature (OAT) for both the pre and post conditions. For the Pre-condition, it was assumed that the pumps would both run at maximum power when energized. This value was calculated with the following equation:

$$kW_{\mathrm{Pre}} = HP_{Pump} \times 0.746 \times 0.9$$

Where: HP_{Pump} = Rated Pump Horsepower
0.746 = Conversion from HP to kW
0.9 = Deration Factor

Both the CWP’s and PCHWP’s are equipped with triple duty valves. In the “Pre” case, these valves were shut anywhere from 40-60%. Therefore, “Pre” flowrates are assumed to be constant.

The “Post” CW and PCHW flowrates are assumed to be constant. The VFDs were installed to fine tune the flowrate of each pump running. Once the proper flow is achieved (depending on the number of chillers running at the time) the flow can be assumed to be constant. Flow does not appear to vary at any other time except when chillers are energizing/de-energizing.

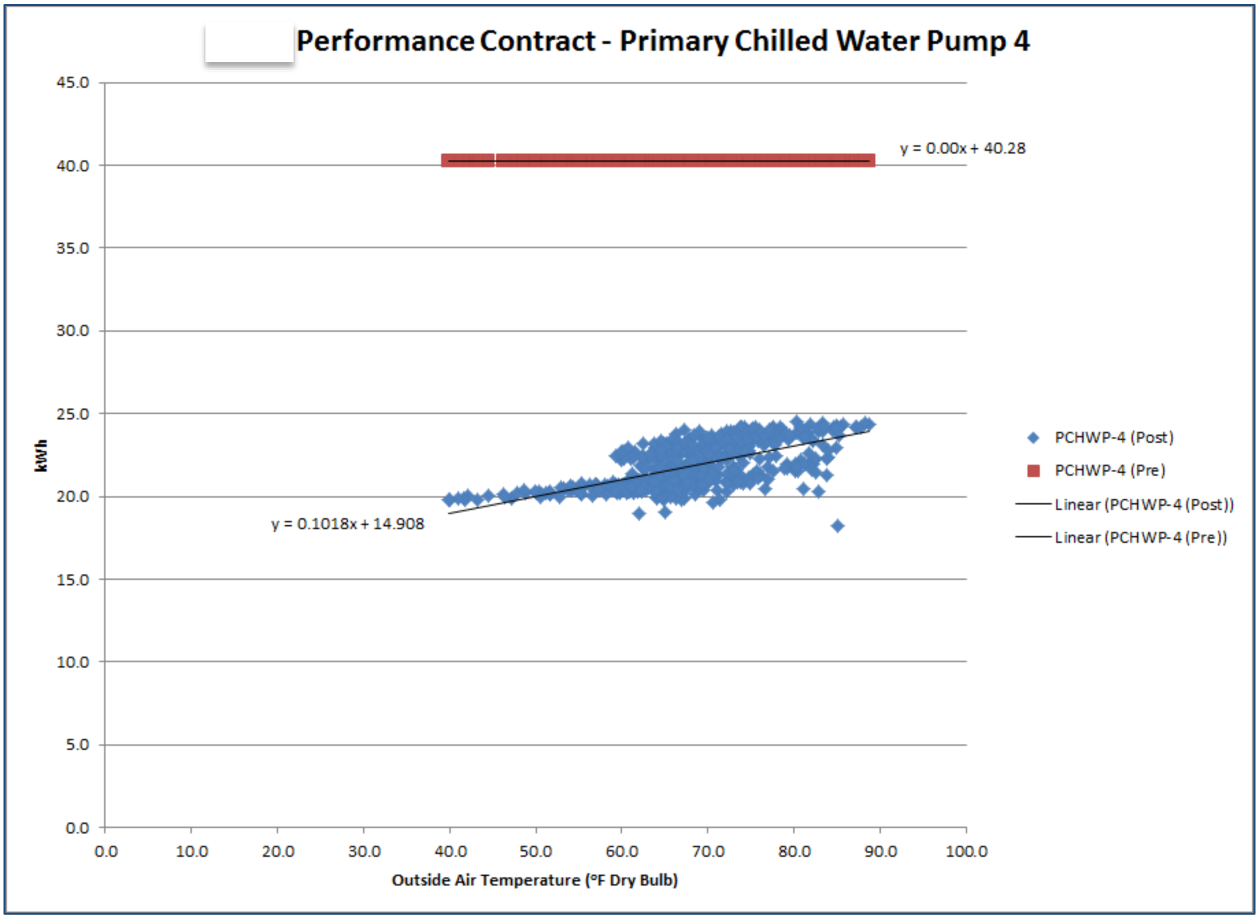

Figure 9. PCHWP-4 OAT Regression

A number of assumptions were made to generate Figure 9 and Figure 10:

- Chilled water and condenser water flows are constant.
- Condenser water pump kW is proportional to chiller plant load
- Chilled water pump flow is proportional to chiller plant load

Condenser water pump data was requested, but not collected. Therefore, condenser water pump kW was assumed to be proportional to chilled water pump kW.

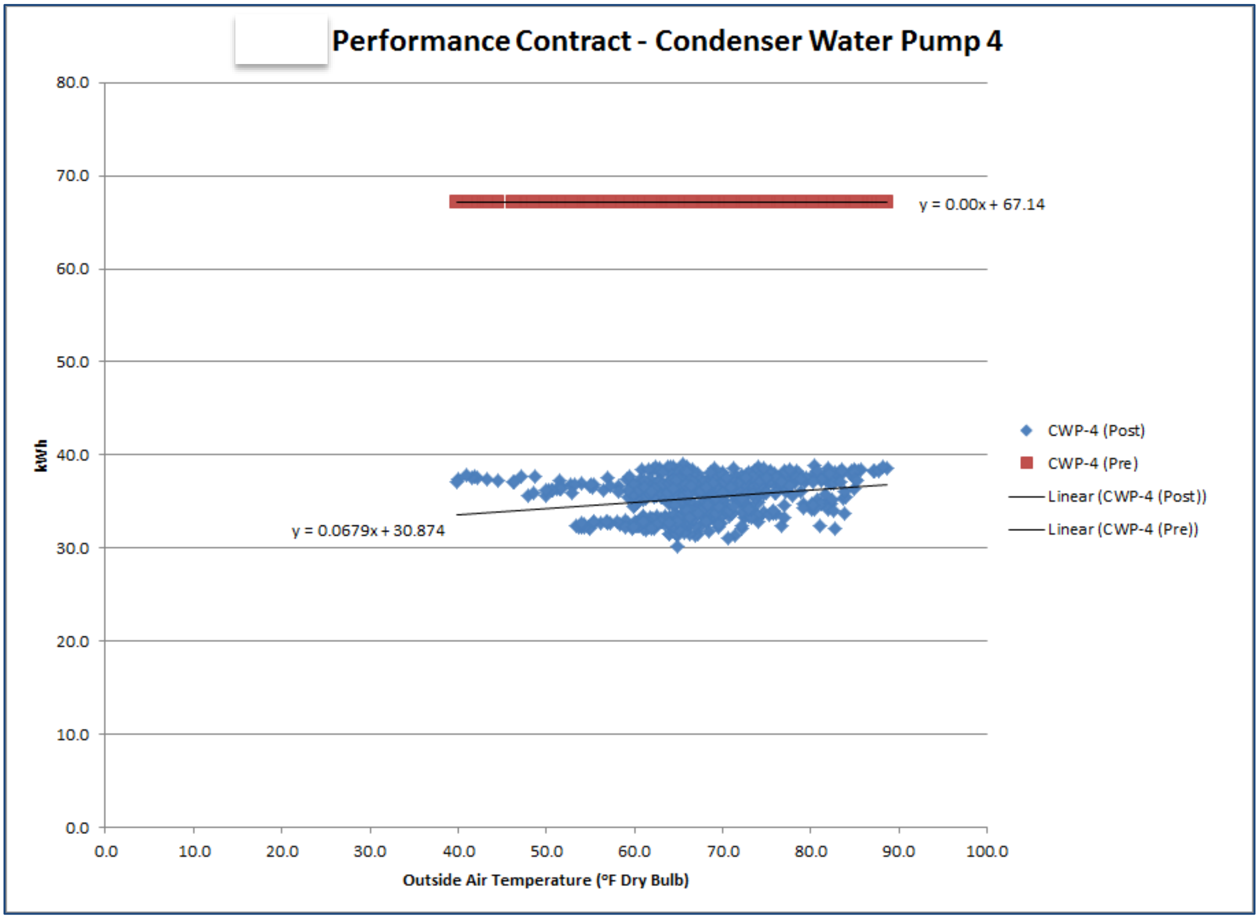

Figure 10. CWP-4 OAT Regression

Figure 11 and Figure 12 were generated by substituting TMY3 data for [redacted], NC into the regression equations found in Figure 9 and Figure 10. Since the chiller staging (and therefore, pump staging) is done automatically by the Tekworkx controller, outdoor air staging temperatures were assumed for each chiller/pump set. Chillers 2 & 3 were assumed to energize in a lead/lag manner over 40°F OAT. Chiller 4 was assumed to run over 40°F OAT and Chiller 1, over 80°F OAT.

Because Chillers 1-3 did not run during the monitoring period, the PCHWP and CWP yearly kWh, coincident peak and non-coincident peak kW values were found by assuming the savings for each of unknown pumps was proportional to the savings for PCHWP-4 and CWP-4. Savings values for PCHWP-2&3 and CWP-2&3 were divided by two to account for the lead/lag operation of these pumps.

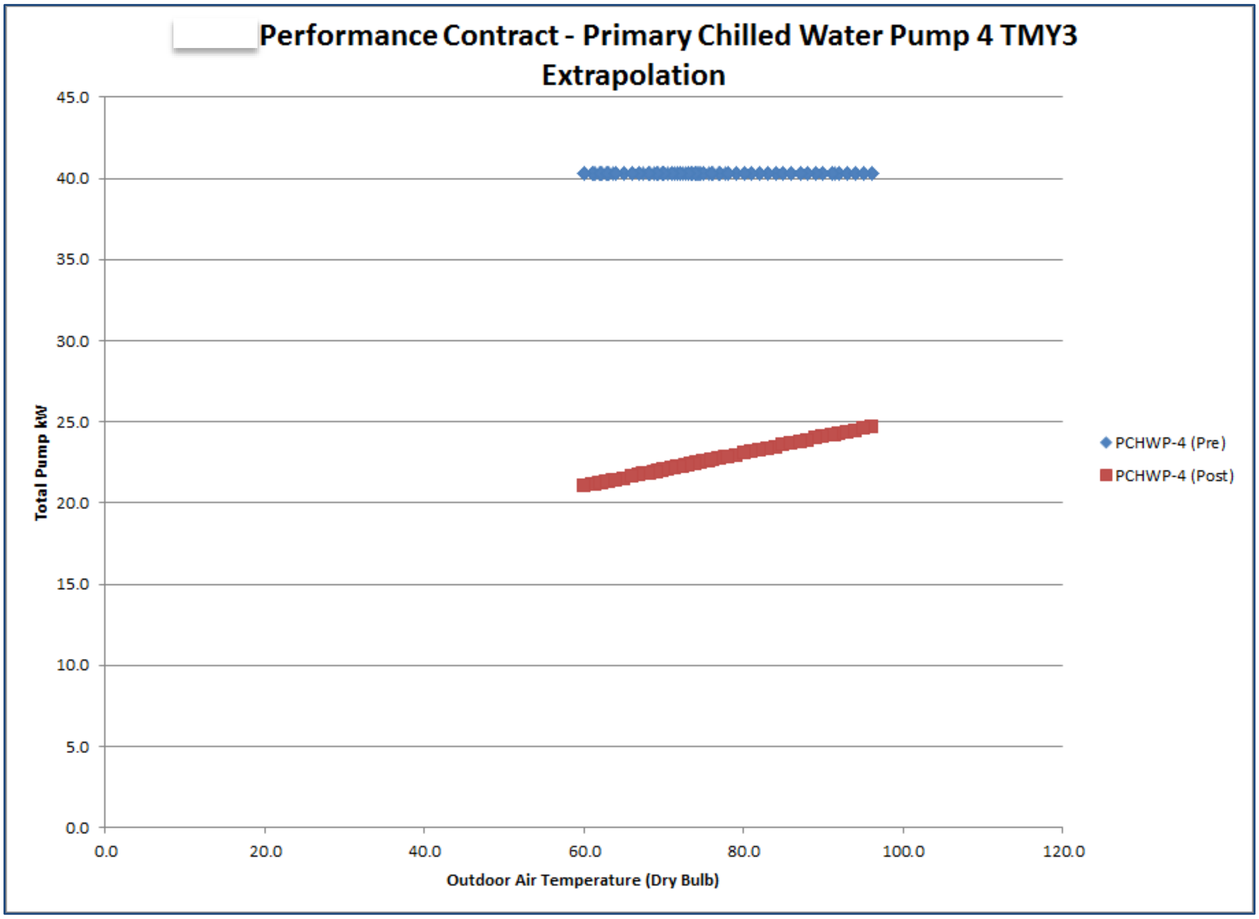

Figure 11. PCHWP-4 TMY3 OAT Annual prediction from regression

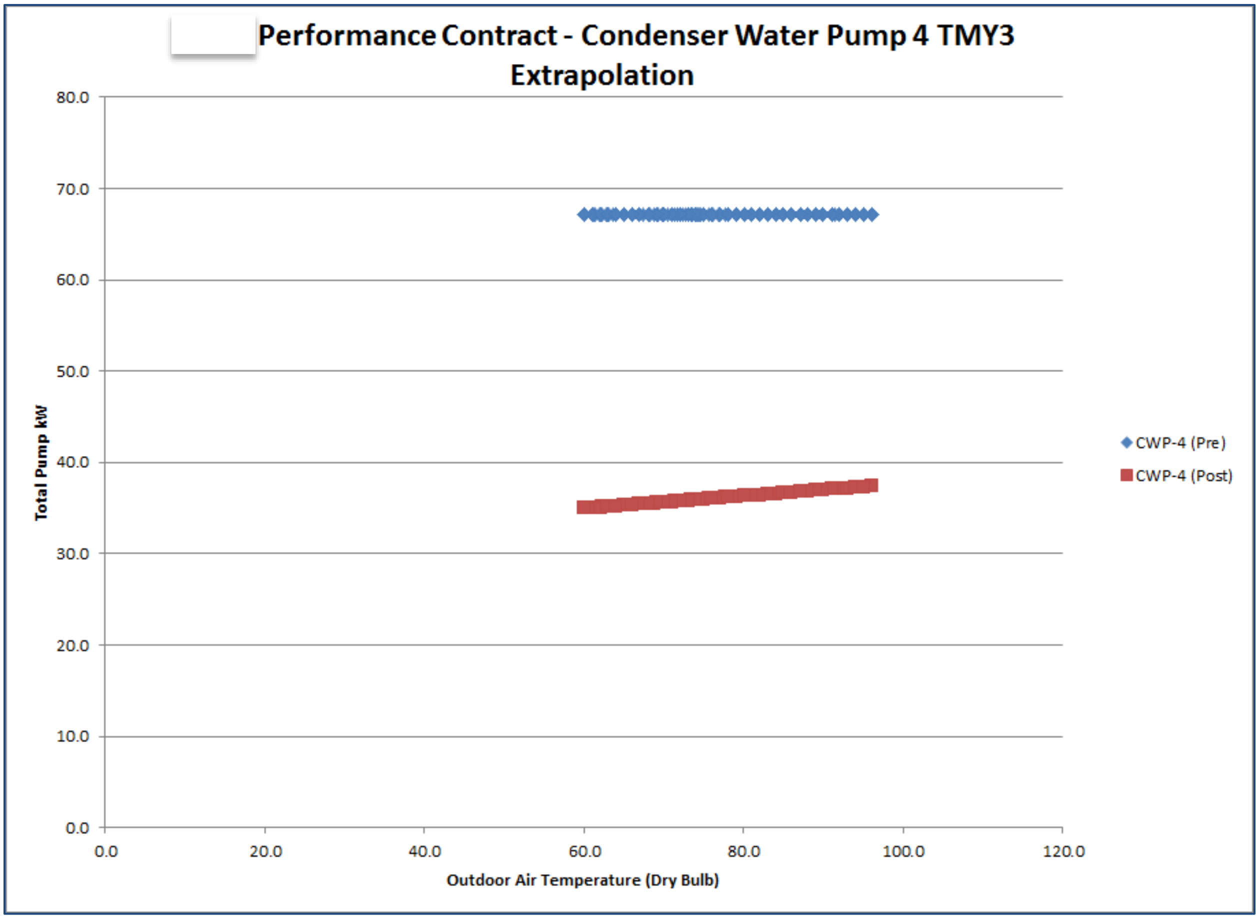

Figure 12. CWP-4 TMY3 OAT Annual prediction from regression

Table 1,

[Redacted] Plant #7 Energy Reduction Results			
ECM	**Actual Savings (kWh)**	**Estimated Savings (kWh)**	**Duke RR (%)**
PCHWP-1	3,417		
PCHWP-2	45,365		
PCHWP-3	45,365		
PCHWP-4	86,865		
CWP-1	7,160		
CWP-2	89,117		
CWP-3	89,117		
CWP-4	151,681		
Total	**518,089**	**1,137,789**	**46%**

Table 2 and Table 3 show the annual savings results for energy, coincident peak and non-coincident peak demand respectively. The monitored data showed that PCHWP-4 had a maximum kW draw of approximately 55% of the nameplate data and that CWP-4 had a maximum draw of approximately 52% of nameplate in the "Post" conditions. The additional VFDs appear to have reduced the overall pump energy consumption.

Table 1. [Redacted] Plant #7 Energy Results

[Redacted] Plant #7 Energy Reduction Results			
ECM	**Actual Savings (kWh)**	**Estimated Savings (kWh)**	**Duke RR (%)**
PCHWP-1	3,417		
PCHWP-2	45,365		
PCHWP-3	45,365		
PCHWP-4	86,865		
CWP-1	7,160		
CWP-2	89,117		
CWP-3	89,117		
CWP-4	151,681		
Total	**518,089**	**1,137,789**	**46%**

Table 2. [Redacted] Plant #7 Coincident Peak Demand Results

[Redacted] Plant #7 Coincident Peak Demand Reduction Results			
ECM	**Actual Savings (kW)**	**Estimated Savings (kW)**	**Duke RR (%)**
PCHWP-1	2.6		
PCHWP-2	5.2		
PCHWP-3	5.2		
PCHWP-4	16.7		
CWP-1	5.9		
CWP-2	11.2		
CWP-3	11.2		
CWP-4	30.5		
Total	**88.5**	**52.6**	**168%**

Table 3. [Redacted] Plant #7 Non-coincident Peak Demand Results

[Redacted] Plant #7 Non-Coincident Peak Demand Reduction Results			
ECM	**Actual Savings (kW)**	**Estimated Savings (kW)**	**Duke RR (%)**
PCHWP-1	2.8		
PCHWP-2	5.6		
PCHWP-3	5.6		
PCHWP-4	15.6		
CWP-1	6.1		
CWP-2	11.4		
CWP-3	11.4		
CWP-4	29.7		

Total	**88.3**	**167.3**	**53%**

Extrapolation to entire project

The results of the sampled buildings and ECMs were scaled to the entire project by applying the individual ECM realization rates to the population. For example, the energy use realization rate for the Variable Frequency Drive ECM at the [redacted] building #1 was 62%. This same realization rate was then applied to all other buildings with that ECM. In this case, both the [redacted] building #6 and the [redacted] building #2 implemented the VFD ECM and so the realization rate *for that ECM* was also assumed to be 62%. Once each ECM realization rate was applied, each building's realization rate was calculated as a weighted average of the individual ECM realization rates.

Results

Once each ECM was calculated and applied to the appropriate buildings, total energy and demand numbers were determined and realization rates were calculated. Final M&V results from the study are shown in Table 4, Table 5, and Table 6.

Table 4. M&V Energy Results

Building	Application Proposed Annual kWh savings	Duke Expected Annual kWh savings	NORESCO M&V kWh savings	kWh Realization Rate of Duke
Building #1	1,212,683	1,212,681	698,671	58%
Building #2	535,039	535,042	284,845	53%
Building #3	419,256	419,254	116,336	28%
Building #4	600,766	613,500	218,100	36%
Building #5	294,638	294,639	81,757	28%
Building #6	317,167	317,164	186,435	59%
Plant #7	1,087,795	1,210,414	518,089	43%
Total	**3,987,344**	**4,602,694**	**2,104,233**	**46%**

The energy use realization rates shown in Table 4 are all less than 100%. This is mostly due to the fact that the "Controls" ECM, which most buildings implemented, does not save as much energy as was assumed in the projections.

Table 5. M&V Coincident Demand Results

Building	Application Proposed Summer Peak kW Savings	Duke Expected Summer Coincident Peak kW Savings	NORESCO M&V Summer Coincident Peak kW Savings	Coincident Peak kW Realization Rate of Duke
Building #1	72	67	196	294%
Building #2	937	93	272	292%
Building #3	94	74	147	200%
Building #4	61	61	53	87%
Building #5	17	14	27	196%
Building #6	40	50	137	274%
Plant #7	79	56	89	159%
Total	**1,300**	**414**	**921**	**222%**

The realization rates for coincident peak demand shown in Table 5 are generally more than 200%. This is mainly due to the fact that the demand reduction from the VFD ECM is much higher than the projections. Typically, a VFD is not expected to reduce peak demand, however in this case the air handling unit supply fans appear to be significantly over-sized. Even during peak cooling conditions, the fans only need to run around 60% of full speed. As a result peak demand savings are considerably more than would normally be expected for the VFD ECM.

Table 6. M&V Non-Coincident Demand Results

Building	Duke Expected Summer Non-coincident Peak kW Savings	NORESCO M&V Summer Non-coincident Peak kW Savings	Non-coincident Peak kW Realization Rate of Duke
Building #1	111	80	72%
Building #2	95	69	73%
Building #3	139	2	1%
Building #4	84	27	32%
Building #5	31	0	0%
Building #6	51	44	86%
Plant #7	178	88	49%
Total	**689**	**309**	**45%**

Application ID 13-1593023
Lighting
M&V Report

August 26, 2016

Duke Energy
139 East Fourth Street
Cincinnati, OH 45201

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Introduction

This report outlines Cadmus' measurement and verification (M&V) activities for seven retrofit energy conservation measures (ECMs) included as part of the [redacted], Smart $aver custom incentive program application—specifically for replacing fluorescent and high-pressure sodium (HPS) lighting fixtures with high-performance fluorescent lighting fixtures at one location in [redacted], North Carolina. Energy savings were expected to result from the reduced fixture quantity and wattage and improved efficiency. Descriptions of the measures as submitted in the original application documentation are provided below.

ECMs 1-7: Replace Fluorescent and HPS Fixtures with High-Performance Fluorescent Fixtures

[Redacted] is a textile manufacturing company located in [redacted], North Carolina. The manufacturing facility contains a warehouse, production floor, water treatment system, mechanical spaces, and offices, operating Monday through Saturday, from 4:00 a.m. to 12:00 a.m. The annual electric energy use is approximately 4,932,000 kWh, based on 2012 and 2013 utility data.

As summarized in Table 1, [redacted] chose to retrofit 1,106 fluorescent T12 and T8 fixtures and one HPS fixture throughout the facility with 520 fluorescent T8 fixtures. All installed fluorescent T8 lamp and ballast model numbers were Consortium for Energy Efficiency qualified. All of the lighting fixtures (both manufacturing and office areas) were expected to operate 6,240 hours annually in the original analysis. The seven lighting ECMs are outlined below:

- ECM-1: Replace one-lamp, 8-foot T12 fixtures with four-lamp, 4-foot T8 fixtures
- ECM-2: Replace six-lamp, 4-foot T8 fixtures with four-lamp, 4-foot T8 fixtures
- ECM-3: Replace two-lamp, 5-foot T12 fixtures with two-lamp, 4-foot T8 fixtures
- ECM-4: Replace a 400-watt HPS fixture with a four-lamp, 4-foot T8 fixture
- ECM-5: Replace four-lamp, 4-foot T12 fixtures with two-lamp, 4-foot T8 fixtures
- ECM-6: Replace two-lamp, 5-foot T12 fixtures with two-lamp, 4-foot T8 fixtures (exterior)
- ECM-7: Replace T12 and T8 fixtures with high-performance, two-lamp and four-lamp, 4-foot T8 fixtures

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Table 1. ECM Summary

ECM	Pre-Retrofit		Installed	
	Description	Quantity	Description	Quantity
1	1-lamp, 8-foot T12	815	4-lamp, 4-foot T8	321
2	6-lamp, 4-foot T8	37	4-lamp, 4-foot T8	21
3	2-lamp, 5-foot T12	10	2-lamp, 4-foot T8	10
4	400-watt HPS	1	4-lamp, 4-foot T8	1
5	4-lamp, 4-foot T12	100	2-lamp, 4-foot T8	100
6	2-lamp, 5-foot T12	4	2-lamp, 4-foot T8	4
7	T12 and T8	139	2-lamp and 4-lamp, 4-foot HP T8	63
Total	**-**	**1,106**	**-**	**520**

The project also involved installing 146 occupancy sensors, which were submitted under a separate prescriptive application.

Goals and Objectives

Table 2 shows the projected savings goals identified in the project application.

Table 2. Project Goals

ECM	Application		Duke Energy			
	Annual kWh Savings	Average kW Reduction	Projected Annual kWh Savings*	Claimed Annual kWh Savings	Claimed Coincident Peak kW Reduction	Claimed Non-CP kW Reduction
1	289,318	N/A	279,146	276,584	44.74	36.59
2	35,256	N/A	33,178	32,874	5.32	5.32
3	2,371	N/A	2,371	2,349	0.38	0.38
4	1,997	N/A	1,997	1,978	0.32	0.32
5	56,160	N/A	56,160	55,645	9.00	9.00
6	3,020	N/A	3,045	3,017	0.49	0.49
7	118,229	N/A	101,144	100,216	16.21	16.21
Total	**506,351**	**N/A**	**477,042**	**472,663**	**76.45**	**68.30**

* Source: DSMore input spreadsheet.

For this M&V project, Cadmus sought to verify actual numbers for the following:

- Facility peak demand reduction (kW)
- Summer utility coincident peak demand reduction (kW)
- Annual energy savings (kWh)
- Annual realization ratios (kW and kWh)

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Project Contacts

Table 3 lists the Duke Energy contact who granted approval to plan and schedule the site visit for this M&V effort, along with the Cadmus contact and the customer contact.

Table 3. Project Contacts

Organization	Contact	Contact Information
Duke Energy	Monica Redman, Senior DSM & Retail Programs Analyst	monica.redman@duke-energy.com
Cadmus	Christie Amero, Senior Analyst	office: 303-389-2509 christie.amero@cadmusgroup.com
Customer	redacted	

Site Location

The site location is listed in Table 4.

Table 4. Site Location

Address	ECM
redacted	1 through 7

M&V Option

To assess this site, Cadmus followed IPMVP Option A.

Implementation

Cadmus reached out to the site contact provided by Duke Energy to review the evaluation plan and to schedule the site visit. Christie Amero of Cadmus performed the site visit on June 22, 2016.

Field Survey

During the site visit, Cadmus met with the facility manager to review the lighting survey and to collect general operating information. The facility manufactures a variety of fabric and produces approximately 45,000 yards of fabric per day. The manufacturing area of the facility operates Monday through Saturday, 24 hours per day, year round. The offices are occupied Monday through Friday, from 8:00 a.m. to 5:00 p.m. The offices observe typical federal holidays, but the manufacturing area has scheduled maintenance during holidays and the lighting fixtures do not shut down.

The office area is conditioned by four split-system heat pumps: three 5-ton units and one 7.5-ton unit. According to the facility manager, the offices are maintained at 72°F year round. The manufacturing spaces are cooled by rooftop units with direct expansion cooling coils. Heating for the manufacturing spaces is provided by a gas-fired steam heating system.

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The facility manager confirmed that the site had all fluorescent T12 lighting fixtures before the retrofit project, and still use a few fluorescents in the shipping and receiving areas. In addition to the T8 lamps, ceiling-mounted occupancy sensors were installed throughout the manufacturing spaces and offices. The facility manager stated that the staff has noticed an improvement in lighting quality in the manufacturing spaces.

Field Data

ECMs 1-7: Replace Fluorescent and HPS Fixtures with High-Performance Fluorescent Fixtures

After completing the lighting survey, Cadmus performed a walkthrough of the facility to verify the installed lighting fixture types and to install light loggers. Figure 1 shows one of the two-lamp, 2-foot by 4-foot fluorescent T8 troffers installed in the office areas and Figure 2 shows one of the four-lamp, 4-foot fluorescent T8 strip fixtures installed in the manufacturing spaces.

Figure 1. 2-Lamp, 2-Foot by 4-Foot T8 Troffer in Office

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Figure 2. 4-Lamp, 4-Foot T8 Strip Fixture in Manufacturing Space

Figure 3 shows the make and model numbers of the installed 4-foot, 32-watt T8 lamp (GE F32T8/XL/SPX50HLECO).

Figure 3. Installed T8 Lamp

Cadmus installed seven light loggers throughout the facility to collect fixture operating hours for a three-week period. Table 5 summarizes the locations of installed light loggers and monitored fixture types.

Table 5. Summary of Fixture Counts and Installed Light Loggers

#	Location	Fixture Description	Light Logger Serial Number
1	Main offices/contract room	2-lamp, 2-foot by 4-foot T8 troffer	10171964
2	Break room	2-lamp, 2-foot by 4-foot T8 troffer	10272509
3	Printers	2-lamp, 2-foot by 4-foot T8 troffer	10161965
4	Panel #6 (sampling area)	4-lamp, 4-foot T8 strip	10282642
5	Panel #18	4-lamp, 4-foot T8 strip	10272701
6	Panel #3	4-lamp, 4-foot T8 strip	10187364
7	Panel #8	4-lamp, 4-foot T8 strip	10187375

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Data Analysis

ECMs 1-7: Replace Fluorescent and HPS Fixtures with High-Performance Fluorescent Fixtures

Cadmus used the survey and light logger data to verify demand and operating hours for the installed lighting fixtures. Table 6 summarizes the light logger data.

Table 6. Summary of Light Logger Data

#	Location	Total Metered Hours	Metered Operating Hours	Percentage Operating	Average Coincidence Factor
1	Main offices	509.9	101.2	20%	50%
2	Break room	509.7	164.2	32%	47%
3	Printers	509.6	105.8	21%	100%
4	Panel #6 (sampling area)	509.3	316.4	62%	100%
5	Panel #18	509.4	392.8	77%	100%
6	Panel #3	508.9	393.6	77%	100%
7	Panel #8	509.0	326.4	64%	100%

The four loggers in the manufacturing and warehouse areas produced a mean projected annual runtime of 6,148 hours and a mean coincidence factor of 100%. The three loggers in office areas produced a mean projected annual runtime of 2,127 hours and a mean coincidence factor of 66%. Cadmus reduced the projected annual operating hours for the four outdoor fluorescent fixtures from 6,240 hours in the original study to 4,380 hours based on anecdotal information from the facility manager. We also reduced the peak coincidence factor for the outdoor fixtures to 0%.

Based on the installed lamp and ballast model numbers collected on site, the total fixture input for the four-lamp, 4-foot T8 strip fixtures is 112 watts, and the total input for the two-lamp, 2-foot by 4-foot T8 troffers is 58 watts. Cadmus adjusted the pre-retrofit T12, T8, and HPS fixture wattages slightly using technical reference manual rated wattages tables. We assumed that the pre-retrofit and installed case fixture quantities were equal to the original application based on sample area counts during the site visit.

The energy savings and peak demand reduction without HVAC interactive effects are 565,042 kWh and 96.09 kW, respectively.

Cadmus also calculated energy savings and demand reductions with HVAC interactive effects, based on the heating and cooling system type collected on site. Cadmus used the waste heat factors listed in TechMarket Works' Process and Impact Evaluation of the Non-Residential Smart $aver® Prescriptive Program in the Carolina System: Lighting and Occupancy Sensors report submitted in April 2013. The energy waste heat factor for a small office near Charlotte, North Carolina with heat pump cooling and heating and no economizer is 0.047, and the demand factor is 0.152. The energy waste heat factor for light industrial near Charlotte, North Carolina with air conditioned cooling, gas heating, and no economizer is 0.113, and the demand factor is 0.194. The following equation is used to calculate savings with HVAC interactions:

$$kWh_{savings\ with\ HVAC} = kWh_{savings}\ x\ (1 + WHFe)$$

$$kW_{savings\ with\ HVAC} = kW_{savings}\ x\ (1 + WHFd)$$

Where:

WHFe = Waste heat factor for energy

WHFd = Waste heat factor for demand

The total evaluated energy savings for the seven ECMs was 627,232 kWh. The evaluated total summer coincident peak demand reduction (for the month of July, Monday through Friday from 4:00 p.m. to 5:00 p.m.) was 114.45 kW, and the average, or non-coincident, peak demand reduction was 71.60 kW.

Conclusion

While on the site, Cadmus found the equipment installed as expected. The overall energy savings realization rate was 133%, compared to Duke Energy claimed savings. The summer peak demand realization rate was calculated as 150%. The average (or non-coincident) peak demand reduction realization rate was 105%.

While the evaluated annual operating hours for all fixture types are lower than that claimed in the original application, the evaluated pre-retrofit fixture wattages were higher and the installed fixture wattages were lower than that claimed in the original application. The original application did not account for HVAC interactive effects, which increased the evaluated energy savings and peak demand reduction by 62,190 kWh and 18.36 kW, respectively.

Table 7 provides a comparison of the applicant, Duke Energy claimed, and Cadmus evaluated energy savings and demand reduction. Table 8 provides realization rates comparing energy savings and demand reductions claimed by Duke Energy to those calculated by Cadmus.

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Table 7. Comparison of Applicant, Duke Energy Claimed, and Evaluation Energy Savings and Demand Reduction

ECM	Applicant		Duke Energy Claimed			Evaluation		
	Annual kWh Savings	Average kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	289,318	N/A	276,584	44.74	36.59	451,074	78.71	51.49
2	35,256	N/A	32,874	5.32	5.32	36,106	6.67	4.12
3	2,371	N/A	2,349	0.38	0.38	4,448	0.78	0.51
4	1,997	N/A	1,978	0.32	0.32	824	0.27	0.09
5	56,160	N/A	55,645	9.00	9.00	22,713	7.70	2.59
6	3,020	N/A	3,017	0.49	0.49	2,015	0.00	0.23
7	118,229	N/A	100,216	16.21	16.21	110,054	20.32	12.56
Total	**506,351**	**N/A**	**472,663**	**76.45**	**68.30**	**627,232**	**114.45**	**71.60**

Table 8. Energy Savings and Demand Reduction Realization Rates

ECM	Annual kWh Savings	Coincident Peak kW Reduction	Non-CP kW Reduction
1	163%	176%	141%
2	110%	126%	78%
3	189%	204%	134%
4	42%	85%	29%
5	41%	86%	29%
6	67%	0%	47%
7	110%	125%	78%
Total	**133%**	**150%**	**105%**